Monitoring and Assessing the Long-term Environmental and Use Impacts on Selected Mountain Bike Trails in South Australia

prepared for
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Executive Summary

This report is of a study to monitor and assess two mountain bike trails in South Australia to look for significant changes under measured use and rainfall conditions. The trails are *Dynamic Tension* at the Mt Crawford Forest, Cudlee Creek Native Forest Reserve Trails Area and *Tunnel Vision* at Eagle Mountain Bike Park. Both are within easy driving distance from the CBD of Adelaide at 43 and 14 km respectively.

The trails were selected: (1) as they were built to guidelines recognised internationally as producing the most sustainable trails; (2) a rider, once started would finish the trail and not take a detour – hence the entire trail would be subject to the same use; and (3) were not likely to have maintenance work carried out during the course of the study. Maintenance was however carried out at one measuring point on *Tunnel Vision* during the study by a team unaware of the importance of not altering the trail for the year. Results are reported on changes to the trail prior to the maintenance work and changes to the trail post the maintenance work were recorded.

The study measured the changes to the cross-section profile and used tread widths at 20 randomly-placed points along each trail. Five sets of profile measurements three months apart were performed over a twelve-month period. Cross-section profiles were gathered by measuring the distances from a horizontal straight edge to the trail surface. Reference marker pegs were set in the ground at each transect measuring point to enable the horizontal beam to be set up in a similar position for each of the five surveys.

Rainfall data were gathered from the Bureau of Meteorology web site listing daily rainfall for the two weather stations closest to the Eagle Mountain Bike Park and the Cudlee Creek Native Forest Reserve. The total rainfall over the study period for Eagle-on-the-Hill (closest to Eagle Mountain Bike Park) was 698 mm and for Stringybark Creek (closest to Cudlee Creek) was 684 mm.

Commercially-available counters specifically designed to record the passage of mountain bikes were used to gather user data on each trail over the full year-long study. The counters were calibrated against manually recorded and time-stamped counts to ensure the best estimates of use from the counter data. The estimated use (without the peaks caused by large events) of *Dynamic Tension* is a mean of 8 to 12 riders per day and that of *Tunnel Vision* is 25 to 30 per day. The overall use estimates for the full year and including the large use for events is about 14 riders per day (approximately 5,100 riders per annum) on *Dynamic Tension* and about 45 riders per day (approximately 16,400 riders pa) on *Tunnel Vision*.

Of the 20 transect points on *Tunnel Vision*, thirteen showed no change to the transect profile discernible using the measurement and observation techniques of this study. Six showed minor but insignificant change. One showed significant change between the March and July 2009 surveys during which time 47 per cent of the rain that fell during the study period occurred and use was about 26 riders per day (about 18 per cent of the total estimated use). No further change was discernible from the July survey to the September survey. The recommended technique of rock armouring the six metre section of trail containing this transect point would significantly increase the sustainability of this section.

Of the 20 transect points on *Dynamic Tension*, eleven showed no change and seven showed minor but insignificant change. One showed soil loss from September to December 2008 (about 12 per cent of rainfall was recorded and about 22 per cent of riders used this trail over this period) and soil deposition from June to September 2009 (40 per cent of the rainfall occurred in this period and about 12 per cent of riders) resulting in a nett zero change in transect profile area over the year.

The other *Dynamic Tension* transect point that showed significant change did so with soil loss between December 2008 and March 2009 (about 9 per cent of rainfall and about 16 per cent of riders). From the March to September 2009 surveys the profile remained stable.

Aggregating the transect profile measurement results from both trails reveals that 60 per cent of the transect points showed no change, 32.5 per cent showed minor, insignificant change and 7.5 per cent (three transect points) showed significant change. On any of the three transects that showed significant change, the most soil loss that occurred across a 1 cm wide strip would fit on a garden trowel. There was no evidence of deep gouging at any of the 40 transect points.

Measurements of the used tread width (where at least 95 per cent of riders would travel) were performed at all 40 transect points: 70 per cent show no change in used tread width, 25 per cent have become narrower and 5 per cent have become wider with none being wider than the surface of the trail as built. The used tread widths were generally between 45 and 50 cm wide.

In summary, the physical properties (transect profiles and used tread widths) of trails built to internationally-recognised guidelines indicate that for the most part trails in the Adelaide Hills can withstand the combination of up to 30 riders per day and 700 mm of rain per annum for at least one year with little impact on the trail surface or the width of the used portion of the trail. Some maintenance is likely to be required in those parts of trails that deviate too far from the guidelines.

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Glossary of Terms, Abbreviations and Acronyms

Term	Description
Cudlee Creek	A commonly-used term for the mountain bike (MTB) trails area officially known as Mt Crawford Forest, Cudlee Creek Native Forest Reserve. The Cudlee Creek MTB trails area is also known by various elements of the cross-country and downhill mountain-biking communities as Fox Creek and Cudlee Fox. The main parking area for the cross-country trails is 43 km from the Adelaide CBD. The parking area at the foot of the downhill trails is about 39 km from the CBD.
Cudlee Fox	See Cudlee Creek.
Eagle MTB Park	Eagle Mountain Bike Park also known as Eagle Park. The northern entrance at the Pastor Kavel Lookout is 14 km from the Adelaide CBD. The southern entrance on Hawk Hill Rd is approximately 21 km from the CBD.
Eagle Park	See Eagle MTB Park.
Fall line	The line of flow of water down a slope.
Fall line angle (°)	On the downslope side, the fall line angle is the direction water would flow away from the point that is on the transect and just outside the tread. On the upslope side the fall line angle is measured from the point on the line of the transect and at the top of the backslope. These two points are usually very close to the respective reference pegs.
Fall line gradient (%)	The gradient along the upslope fall line angle and measured to the point at the top of the backslope and on the transect line.
Fox Creek	See Cudlee Creek.
IMBA	International Mountain Bicycling Association. Based in the US, this body's mission is to protect, create, and enhance quality trail experiences for mountain bikers worldwide. IMBA also actively promotes responsible mountain biking, supports volunteer trailwork, assists land managers with trail management issues, and works to improve relations among trail user groups.
MTB	Mountain bike
MTBA	Mountain Bike Australia. The controlling body for the sporting aspects of mountain biking in Australia.
Reference pegs	Engineering set-out pegs placed in the ground and used as the markers from which to set up the transect profile measuring apparatus. The direct line between the Upside Reference Peg and the Downside Reference Peg forms the transect across which the cross-section or profile is measured.
Sideslope gradient	The gradient of the hillside perpendicular to the trail. Measured from the point at the top of the backslope and on the transect line.
Single-track	A trail that is wide enough for one rider only.
Trail angle	The angle of the trail at a transect point. The angle is referenced to magnetic north. Measured in both directions from the middle of the used tread at the transect: (a) looking back towards the nominated start of the trail and (b) looking forwards towards the end of the trail.
Trail gradient/incline	The slope of the trail at the transect point.

Trail to fall line angle	The angle between the trail and the upslope fall line. The ideal angle is 90 degrees.
Transect	The plan view line between the reference pegs at the transect point. The transect is intended to be perpendicular to the trail.
Transect point	Point on the trail at which the transect cross-section, gradients and relevant angles are measured.
Tread	That part of the trail built to be ridden. Also known as the full tread or bench.
Used tread	That part of the tread that is actually ridden.

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1 Introduction

1.1 Impetus

Mountain biking (MTB) has become increasingly popular in Australia since about the mid-1980s after its beginnings in the early 1970s in the USA. Early mountain bike tracks were often old vehicle tracks that were established with little or no regard to principles of limiting their impacts on the environment. Mountain Bike Australia (MTBA), the peak Australian body responsible for the competitive aspects of mountain biking, has for many years expended considerable energy encouraging the building of single-tracks to the guidelines generated by IMBA (the International Mountain Bicycling Association headquartered in the US).

These guidelines (International Mountain Bicycling Association (2004); and see International Mountain Bicycling Association (2007) *Managing Mountain Biking*) encourage the design and construction of “environmentally sustainable” trails which are defined (International Mountain Bicycling Association (2007) *Managing Mountain Biking*) as:

- Protecting the environment;
- Requiring little maintenance;
- Meeting the needs of users; and
- Minimizing conflict between user groups.

In particular, “protecting the environment” encompasses limiting deleterious effects on local fauna and flora, and “requiring little maintenance” aims for trails with long-term resistance to erosion from natural forces, and wear through use. It is this definition of sustainable that is used in this report.

Mountain Bike Australia has been active in promoting best practice through sponsoring IMBA trail design and construction workshops and through disseminating information to mountain bike members and clubs. MTBA has worked closely with land managers within local and State/Territory governments to encourage the building of sustainable trail networks. Through the work of MTBA, IMBA and many committed track-builders, the proportion of approved single-tracks now being built in Australia and constructed to IMBA guidelines is increasing. With MTB track-building progressing in many areas of the country, MTBA is particularly interested in building a picture of how cross-country single-tracks built to the sustainable guidelines in all parts of Australia fare under the local conditions of use, soil type and rainfall.

Previous studies conducted in other parts of the world have been in essence a once-only record of trail characteristics. This report covers twelve months and is the first longitudinal study of MTB trails designed and constructed according to the IMBA guidelines for building sustainable trails.

1.2 Location

The study focused on two MTB single-tracks in South Australia. Both of the tracks were built according to the IMBA guidelines and each has had several years of use during which time they have ‘bedded in’.

One of the single-tracks studied is *Dynamic Tension* in the Cudlee Creek Mountain Bike Trails Area. This area is officially called Mt Crawford Forest, Cudlee Creek Native Forest Reserve and is known colloquially as Cudlee Creek, Fox Creek or Cudlee Fox. The vehicle parking area most often used to access this trail is about 43 km by road to the east of the Adelaide CBD. The distance by bike is shorter at about 33 km as the trails area lies adjacent to and in some places incorporates the Mawson Trail, South Australia’s iconic long-distance mountain bike trail. The trails area is characterized by sections of open grassland, plantations of *pinus radiata* and sections of native forest. *Dynamic Tension* is on a hillside that has seen the rapid re-growth of native vegetation – in particular gum trees – in the few years since the trail was commissioned in 2005 (see Figure 1 and Figure 2).

Figure 1 Panorama of part of *Dynamic Tension* (June 2009). This section of trail (running roughly horizontally across the middle of the photograph) contains transect points 1 to 15

Figure 2 View of transect points 3 to 5 of *Dynamic Tension* (September 2009)

The other single-track of the study is a section of *Tunnel Vision* in Eagle Mountain Bike Park (Eagle MTB Park). The Pastor Kavel entrance on the north side of this purpose-built MTB area is 14 km from the Adelaide CBD on the Eagle on the Hill Rd (the old Princes Highway before the building of the Adelaide-Crafers Highway through the Heysen Tunnels) heading south-east of the city. The southern entrance (Hawk Hill Rd) is some distance further by road: approximately 21km from the CBD.

Eagle MTB Park is on the site of an old quarry that subsequently was used as the dumping ground for material excavated during the construction of the Adelaide-Crafers Highway. There is an on-going program of re-vegetation, weed eradication and trail maintenance under the care of several groups of volunteers (Friends of Eagle, Green Corps, Conservation Volunteers Australia, Correctional Services Day-release Volunteer Program, Adelaide Mountain Bike Club, Inside Line Downhill Mountain Bike Club) managed by the Office for Recreation and Sport. Eagle MTB Park has areas of vegetation of significant value and in these areas no trails have been built nor are they likely to be built in the foreseeable future. *Tunnel Vision* itself is on the eastern side of a ridge and is characterised by open gum woodland and grasses.

The trail itself winds around and along the side of the ridge and does not lend itself to a panoramic view like that above of *Dynamic Tension*. Figure 3 has four views of the study section of *Tunnel Vision*.

Figure 3 Views of *Tunnel Vision*. Clockwise from top left: from the nominal start of the study section (September 2008); the trail on the dam wall between transect points 8 and 9 (September 2009); tree obstacle between transect points 16 and 17 (September 2009); and looking back from transect point 13 (September 2009).

1.3 Focus

The study looks at soil movement through displacement and erosion from each of the trails by observing the changes to the cross-section profile of the trail at 20 transect points along the trail. Changes to the used tread width (ie where at least 95 per cent of riders travel) are also measured. The technique is to measure changes in the cross-section of the track (ie shape and area) at the transect points using a horizontal beam set up in the same position for each of the five quarterly measurements over the year.

2 Methodology

2.1 Trail Selection

The two MTB trail areas of the study (Cudlee Creek and Eagle MTB Park) were at the time of the commencement of the study, the only two within 45 minutes drive of the Adelaide CBD that have at least a considerable proportion of their trails constructed using the IMBA guidelines. Each trail chosen from the two areas is of sufficient length to give a range of topographies across the transect points and typical of the area. Each trail has only one entrance and exit point which makes it highly likely that a rider, having begun will complete the entire trail, and not take a diversion. This gives as high a representation as possible that the use for each of the sampling points along the trail is the same.

2.2 Transect Points

The transect points are located equidistantly along the trail with the position of the first being randomly determined relative to the trailhead; thus all points are regarded as randomly positioned. The transect points are marked with reference pegs set into the ground and close to flush with the surface. The pegs can be covered to offer minimal, if any, distraction to riders and can be uncovered easily for survey purposes.

The pegs are labeled Upside Reference Peg (URP) and Downside Reference Peg (DRP). All potential transect point locations except the apex of climbing and descending turns have a clear upside and downside. Only one transect point (#3 on *Dynamic Tension*) is nearly on the apex of a turn and comes close to having both of its reference pegs at the same height.

The pegs serve two somewhat conflicting purposes: they must be unobtrusive so the riding pattern of trail users is unchanged; and they must be reasonably easy to locate for subsequent measurements. During informal chats with users it is clear that the pegs have not impacted on riding behaviour and some were unaware of their existence even after several rides of the trail. Most of the pegs have been relatively easy to find in each survey: none have taken more than two minutes to locate. Only once has there been a need to use the triangulation information recorded during the initial placement of the pegs. This triangulation consisted of measuring distances from each peg to large, static objects nearby eg trees and rocks.

2.3 Observation Timing

The study consists of five sets of observations scheduled three months apart over the year of the study. This report covers all five sets of observations. These were performed in September and December 2008, March, June or July and September 2009.

2.4 Transect Profile

2.4.1 Measuring Method

A transect profile (cross-section of the trail) is found by measuring the vertical distance from a horizontal straight edge to the trail surface at several measuring points along the trail transect (Figure 4). The transect is the plan view line between two reference pegs: the upside reference peg (URP) and its downside counterpart (DRP) placed each side of the trail. The straight edge is mounted on tripods and positioned so that the edge of the beam from which the measurements are taken is directly above the holes drilled into the middle of the top surface of each of the reference pegs. Accuracy is achieved using plumb bobs dropped from the straight edge to the pegs. Similarly, the vertical distance from the straight edge to the trail surface is found by dropping a plumb bob to the trail surface. A flat, steel tape measure is clamped to the top of the beam, and positioned so that the horizontal distance of each measuring point from the upside reference peg is recorded. A view of the apparatus setup is shown in Figure 4.

The extent of the measurement is governed by what is adjudged to be the used tread width. The used tread width is bounded by the Upside Tread Boundary (UTB) and the Downside Tread Boundary (DTB). The used tread is defined as that part of the full tread that is used by at least 95 per cent of riders. The UTB and DTB are adjudged in the first (baseline) survey and are two of the reference points at which measurements are taken during each survey. If, during a subsequent survey, the used tread width is adjudged to have changed, then the new used tread boundaries are labelled UTB′ and DTB′. Measurements are taken at these new boundaries **and** at the original UTB and DTB to enable a comparison of the transect profiles.

The transect boundaries of the second profile extend to 20 cm either side of the used tread. These boundaries are referred to as the measuring limit and are designated the Upside Measuring Limit (UML) and the Downside Measuring Limit (DML). Similar notation is used (ie UML′ and DML′) when the used tread width is adjudged to have changed. Measurements are then taken at all of the reference points.

Figure 4 Transect profile measurement setup

The method for determining each measuring point along the transect follows that given in Marion and Olive (2006) called the “variable interval cross-sectional area method”. This is “an adaptation of the traditional fixed-interval method” and is preferred due to (a) its improved accuracy in determining the shape of the profile when compared with the fixed-interval method; and (b) where tread surfaces at the transect are smooth rather than grooved or rocky, the measurement time can be reduced.

The variable interval CSA method reduces the profile of the tread across the trail (ie the transect) to a series of connected straight lines between the points where the transect visibly changes its cross-section slope (the “micro-topography”) (see Figure 5). This method enables a more complete and accurate calculation of the cross-sectional area than measuring at points at regularly-spaced intervals (eg every 50mm) across the transect though care must be taken to ensure that the subjectivity involved in the selection of the measuring points is reduced as much as possible.

Figure 5 shows a representation of a trail profile with the natural line of the hillside to the extreme left and right of the diagram. The horizontal straight edge is supported by tripods. The plumb bobs are shown over the reference pegs URP and DRP. The used tread width boundaries are indicated with UTB and DTB and the full measuring width boundaries 20cm each side of the used tread width are indicated with UML and DML.

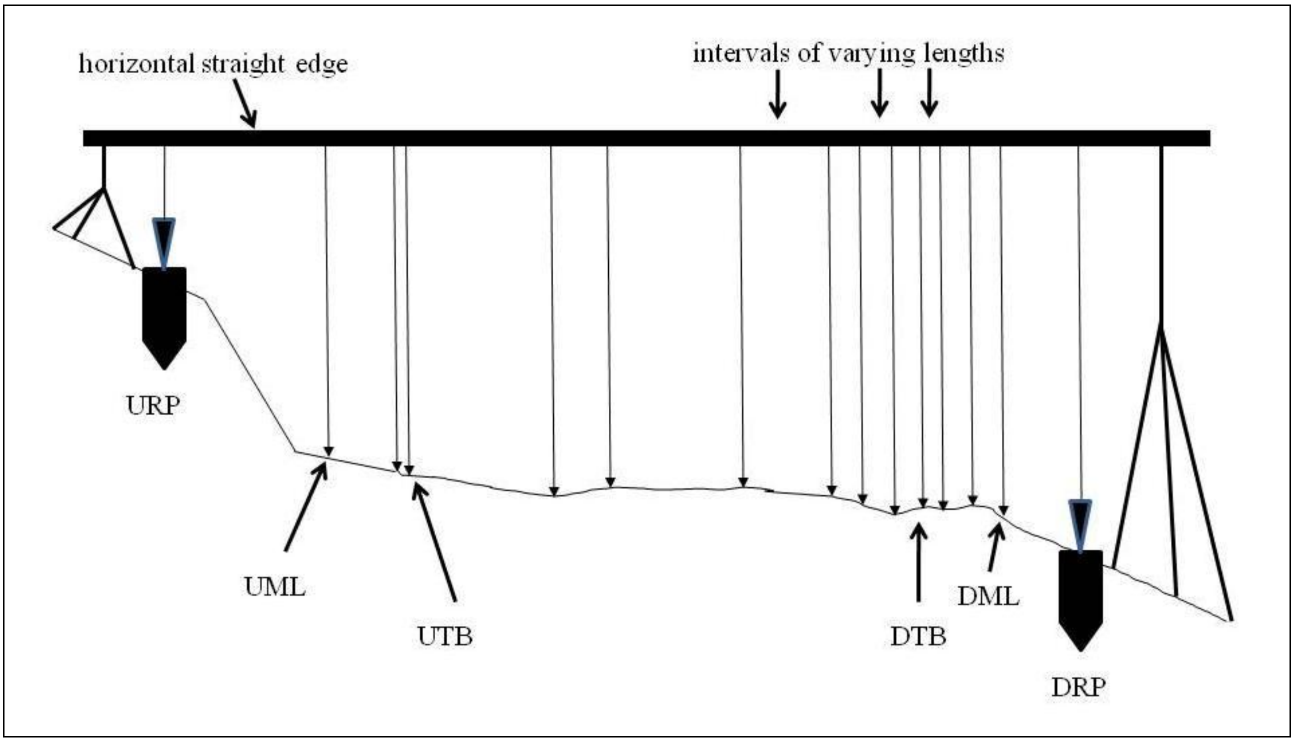

Figure 5 Diagram of the variable interval cross-sectional area method

2.4.2 Sources of Error

There are several sources of possible error associated with the method of using a horizontal straight-edge located directly over the reference pegs. The errors can occur in the following actions:

- the positioning of the straight edge by using plumb bobs over the reference pegs;
- the positioning of the measuring tape on the top of the straight edge relative to the upside reference peg;
- the judgement of ‘level’ by using a builder’s level to set up the horizontal straight edge;
- the judgements involved in reducing the transect profile to a series of straight lines; and
- measuring errors for all vertical distances.

A close-up view of how the plumb bob is positioned over a reference peg is shown in Figure 6. The accuracy can be affected by wind, the stability of the tripod holding the horizontal bar and of course the ability of the operator to adjudge the required position of the plumb bob with respect to the reference peg. Note the small hole drilled into the top of the reference peg to improve the consistency of positioning. When taking the measurements and placing the tripods in particular, care is taken to disturb the vegetation and land forms as little as possible.

The compounding and confounding factor in performing the measurements for this study is that the measurements are performed more than once. While each of the above sources of error are present when performing a one-off study of a trail, the nature of performing five sets of measurements on each of the transect points of a trail means that the likely range of the error must be considered when drawing conclusions from the analysis of the measurements and subsequent calculations. For these reasons a small change in profile area between one survey and another may well be due to measurement errors and hence it is unwise to conclude that there has been either soil loss or gain for mean change in profile area values of less than 1.0 cm^2/cm. To be able to improve the accuracy would require a much more sophisticated (and more expensive) measuring technique capable of millimetre accuracy

Figure 6 Positioning the plumb bob over a reference peg (TV-6 March 2009)

The most difficult vertical distance to measure was most often the Upside Reference Peg (URP) height. Due to the comparatively short distance between the top of the horizontal bar and the top of the peg, any errors in measurement constitute a higher percentage of the height than the same size error with respect to the Downside Reference Peg (DRP) height. It is the URP height that is used as the height reference for the graphs and the transect cross-section profile calculations. Any variation in this one measure or in the positioning of the measuring tape on the top of the straight edge for any one survey can be seen on the graph of the profiles as a vertical shift in the profile. Where this shift is apparent and the shape of the profile is consistent with other surveys, it can be concluded that there has been insignificant change in the profile regardless of the mean change in cross-sectional area.

2.5 Transect Profile Cross-Section Area Calculation

The nature of the measuring technique means that it is very difficult to set up the horizontal bar in the second to fifth surveys at the same height above URP and DRP as it was set in the first (baseline) survey. There is no real need to do this as the height can be 'standardised' post-survey by a simple subtraction/addition process using a spreadsheet. This technique also enables the profiles for a transect point to be graphed in a consistent manner.

Two profile cross-section areas are calculated for each transect point for each survey: the area bounded vertically by the used tread edges (ie the used tread profile bounded by UTB and DTB); and the area bounded a further 20 cm beyond the used tread edges (ie bounded by UML and DML).

When comparing the cross-sectional area from one survey with that of another, the same bounds are used. For example, when comparing the used tread profile of Survey #5 with that of the baseline survey #1, the UTB and DTB distances from the URP are the same. That is, a measurement of the profile is taken at the same reference point distances from the URP in each survey. The exact places where measurements are taken along the trail transect between these two reference points may change due to: (a) changes (wear, erosion) in the trail tread; and (b) differing judgements as to where the profile visibly changes its slope (see Section 2.4.1). Note that even though the used tread width may change, measurements are still taken at UTB and DTB as defined by the baseline survey.

Profile measurements were taken at the same UTB, DTB, UML and DML distances for the September 2008, June/July and September 2009 surveys and hence calculations for the cross-sectional areas for these surveys is straightforward. For the December 2008 and March 2009 surveys, measurements at the baseline reference points at many transect points were inadvertently omitted as the width of the used tread was adjudged to have changed slightly at these transect points. Hence to compare the used tread profiles of the September 2008 survey with those of December 2008 and March 2009, interpolation of the measured data was carried out to ascertain the height at the UTB and DTB as defined by the September 2008 survey. A similar process was performed to find the height at the UML and DML reference points for the full measuring width.

Once the height of the bar is standardised and the profile reference points are corrected where necessary, the cross-sectional area of the profiles for each survey can be calculated.

2.6 Analysis

2.6.1 Profile Areas and Used Tread Widths

The study seeks to find any significant changes between the cross-sectional areas at any of the 40 transect points over the course of the five surveys. The methods for doing this are:

- analysing changes in profile cross-sectional areas;
- graphing the profiles; and
- visual inspection aided by photographic record.

Combining these ensures the best interpretation of any differences to the trail at the transect points: one method is used to back up the other.

At each transect point two cross-section profile areas are calculated. The inner profile extends to the boundaries of the used tread width (ie from UTB to DTB). The outer profile extends to the boundaries of the measuring limit.

The measure used for comparing cross-sectional areas is the mean change in profile area. This is calculated as the area between the two profiles being compared at the transect point (eg Survey #2 cf Survey #1), divided by the distance over which the profiles are measured. The unit is given as square centimetres per centimetre (cm^2/cm). A positive mean change means the baseline profile (ie the profile from the first survey) as measured is below the compared profile from the later survey (ie this may indicate soil gain). As an example, if the difference in cross-sectional areas for the width of the used tread is calculated as 10 cm^2 and the width of the used tread (UTB to DTB) is 100 cm, then the mean change is 0.1 cm^2/cm.

The reference points, used tread and measuring widths and the mean change results are shown in the document entitled *Appendix D: Measures of Transect Profile Change.* The graphs of the profiles for each transect point are shown in *Appendix C: Transect Profiles.*

An example of a graph of the transect profiles from a transect point that showed no discernible change over the study period is shown in Figure 7. This is point #1 on *Tunnel Vision* and the mean change in used tread width profile area values associated with this transect point when Survey #1 is compared with the four later surveys are: 0.7, 0.9, -0.1 and -0.1 cm^2/cm. The corresponding measuring limit profile area values are: 0.8, 1.1, 0.2 and 0.2 cm^2/cm. Even though on first inspection these figures suggest there was some change evident, these figures are typical of a transect point that has not shown discernible change.

As discussed in Section 2.4.2 there are occasions when the measurement errors confound to produce a mean change value that on first inspection may indicate significant change. This is where using the profile graphs, photographs, and visual inspection in conjunction is helpful in drawing conclusions about that particular transect point ie concluding if there has been no change, there has been minor change but insignificant, or there has been significant change.

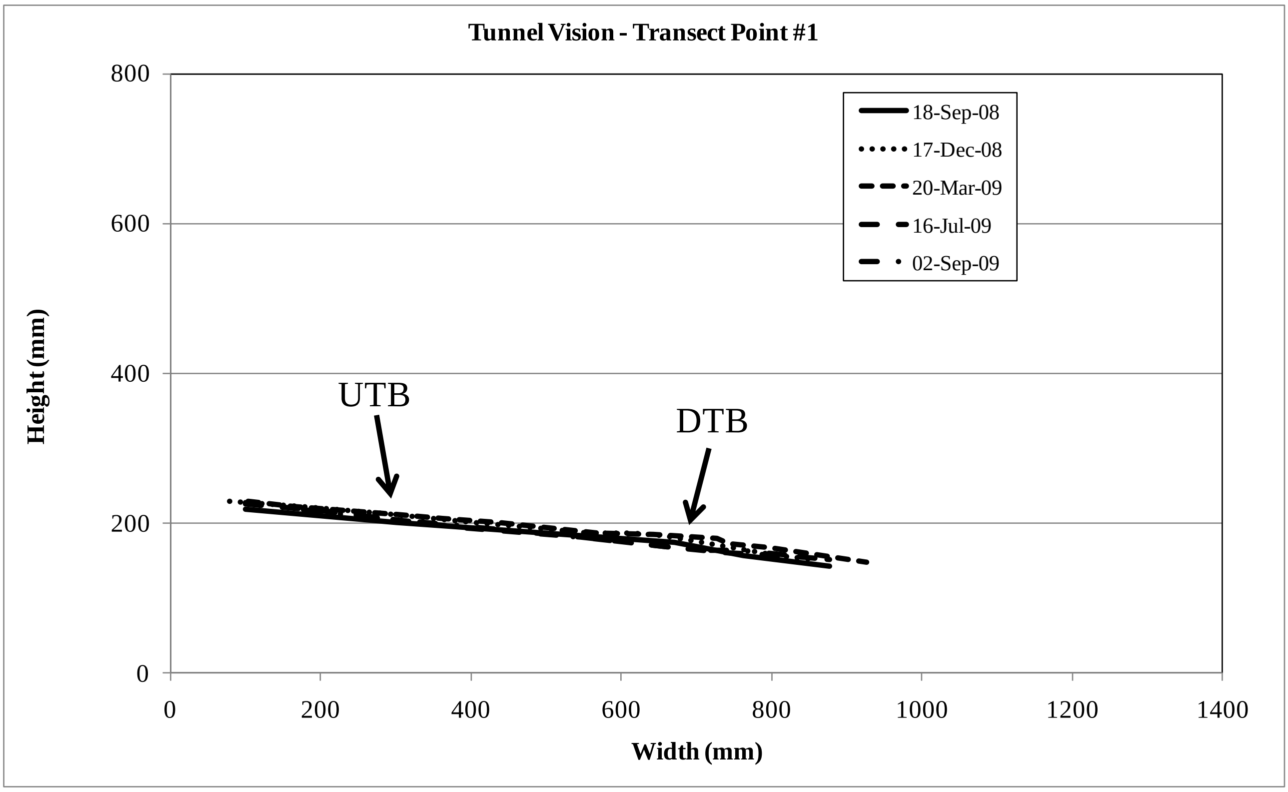

Figure 7 Example profile graph of a transect point exhibiting no change in cross-sectional areas over the study period

Where the graphs of each of the profiles have similar shape but may be vertically displaced by a small amount, it can be assumed that the errors as discussed above have compounded to produce a larger mean change value than reality would suggest.

An example of this vertical shift due to measurement error in the URP of the baseline survey is given in Figure 8 where it could appear that the entire width of the trail is wearing and eroding at a remarkably similar rate. This is unlikely to occur and is not the case here. The mean change in used tread width profile area values associated with transect point #5 on *Tunnel Vision* when Survey #1 is compared with the four later surveys are: -1.0, -1.3, -0.7 and -0.8 cm^2/cm respectively. If the measurement for the height of the URP is in error by 9mm in the first survey then the four compared values become: -0.1, -0.4, 0.2, and 0.1 cm^2/cm and the subsequent graph is more akin to that of Figure 7 describing transect point #1 ((ie the vertical displacement between each profile line on the graph is much smaller than in Figure 8). Hence where the profiles have very similar shape but are vertically displaced, the profiles are described as ‘consistent’.

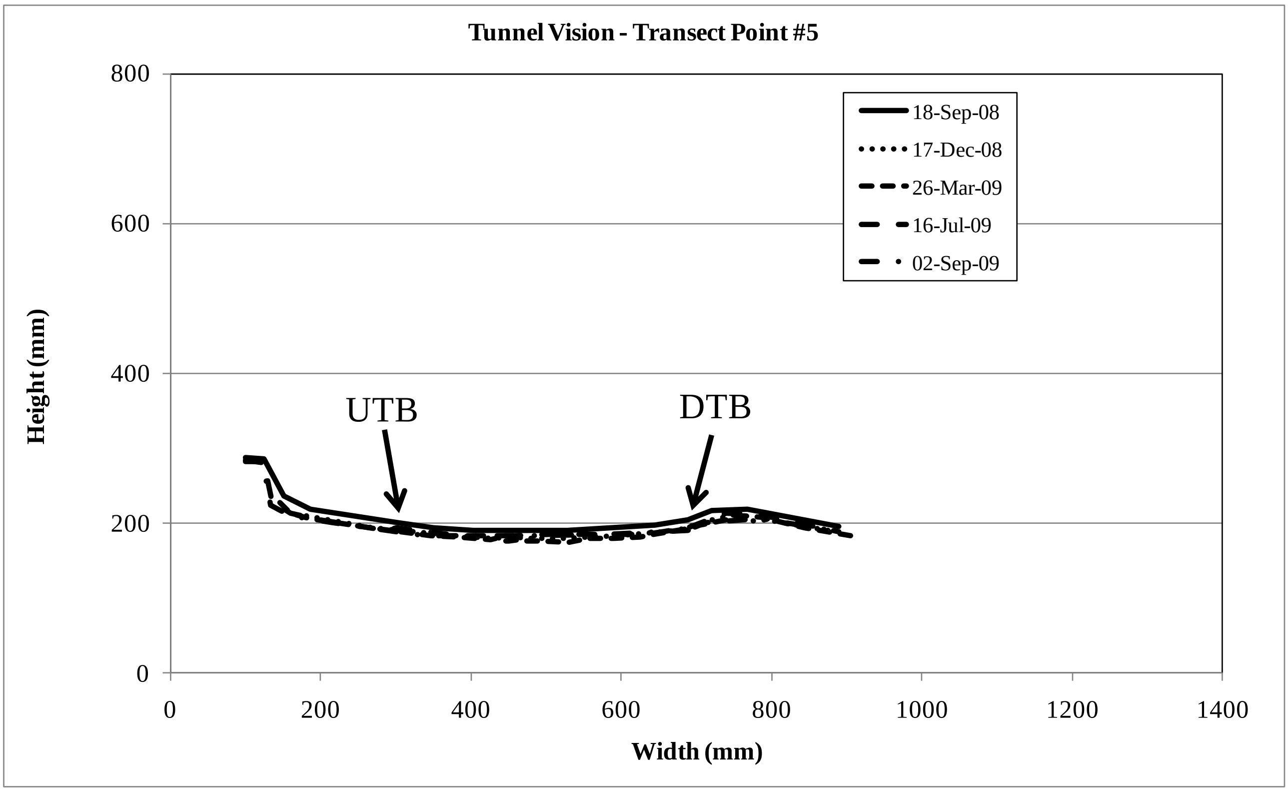

Figure 8 Example of a consistent set of transect profiles

Transect point topography characteristics of a transect point (eg trail gradient, trail to fall line angle) can assist in understanding the nature of wear and erosion at the point. The relevant topography details are contained in *Appendix B: Transect Point Topographies*. See Section 6 for descriptions of these characteristics.

2.6.2 Soil Movement

What are the possibilities for soil movement in relation to trails? There are two reasons why soil moves from/along/to trails: (1) the action of users (humans and animals); and (2) the action of wind and water. Additionally there are two points of view to take into consideration: from the point of view of a longitudinal section of trail of (say) several metres and the point of view of the transect of the trail across the tread. From the longitudinal section point of view, soil that moves within the confines of the tread is soil movement but is not lost (or gained).

From the point of view of a transect there are three considerations. Soil that moves longitudinally along the trail but stays on the trail is soil loss or gain since it is lost from or moves into the transect. Soil also moves within the tread (intra-tread) and to and from the outside of the tread (extra-tread) constituting a loss or gain of soil. With the emphasis in this study on transect measurements, the transect point of view is taken and no attempt is made at extrapolating the measures to estimate the longitudinal view. Note that Marion and Olive (2006, p19) extrapolated their cross-sectional area findings to either side of the transect points to estimate soil loss from segments of trail.

Soil displacement is concerned with effects from users (IMBA (2004) *Managing Mountain Biking*, p101) and consists of three elements: (1) soil displaced from the tread to outside the tread boundary; (2) soil displaced from one part of the tread to another; and (3) soil moved along the trail.

Soil displacement can occur on mountain bike trails where soil is pushed to the outside of the tread. This can occur on any section of trail including straight and flat sections and could result in a concave profile. On corners (in particular descending corners) this can create or add to a berm of soil (a berm is a raised bank or ridge of soil or material on the outer edge of a corner and can significantly aid cornering). Such displaced soil can impact nearby vegetation (eg cover vegetation). Displacement also occurs along the most used part of the tread through speed and braking and even lateral movements of the bike. Soil displaced to the outside of the tread can create a bermed edge which can trap water on the trail. Such displaced soil is not usually lost until rain falls, and due to the trapping nature of the modified tread, erosion is more likely to occur.

The term "erosion" refers to the effects of wind and water to whatever degree (IMBA (2004) *Managing Mountain Biking*, p101). Debilitating erosion (eg heavy rain and driving wind) is specifically concerned with the gouging of one or more deep grooves in the tread surface. These deep grooves are not caused by human or animal activity eg tyres and hooves. More gentle or benign erosion can be responsible for soil movement at a transect point in the same three ways (longitudinally, intra-tread and extra-tread) that it moves from the actions of users (displacement).

To differentiate quantitatively between soil moved due to users and that moved due to wind and water would require the use of control trails that would experience no use whatsoever or would experience exactly the same use but would not be affected by wind and water. Neither of these options is workable, hence this study does not refer solely either to soil displacement as that is concerned with users or solely to erosion as that is concerned with wind and water.

Of the three ways soil moves from a transect point of view, that of extra-tread soil movement (from the tread to the outside and vice versa) is considered in this study by taking the measurements to 20 cm either side of the baseline used tread width along the transect. Intra-tread soil movement is considered by measuring the changes in the profile of the transect. The third of these is impossible to measure using a pure transect technique but Marion and Olive (2006, p19) extrapolated their cross-sectional area findings to either side of the transect points to estimate soil loss from segments of trail. This technique relies on several assumptions and is not considered in this study.

3 Rainfall

Rainfall data are taken from the publicly-available Bureau of Meteorology web site. The relevant weather stations form part of the River Torrens Catchment, 1st to 5th Creeks Section. The nearest stations to Eagle Mountain Bike Park and the Cudlee Creek Trails are Eagle-on-the-Hill and Stringybark respectively. It is reasonable to assume that the difference in actual rainfall between the respective nearest weather stations and the study areas is negligible.

The rainfall patterns for the study areas are similar: some small falls through the Spring of 2008; heavy, short-duration falls in December, March and April with minimal precipitation in between; then regular falls through the winter of 2009 into the Spring.

The Eagle-on-the-Hill station recorded 698 mm over the study period (11 September 2008 to 10 September 2009) and the Stringybark station recorded 684 mm. This represents a difference of just over 2 per cent. The cumulative rainfall curves for both weather stations are shown in Figure 9.

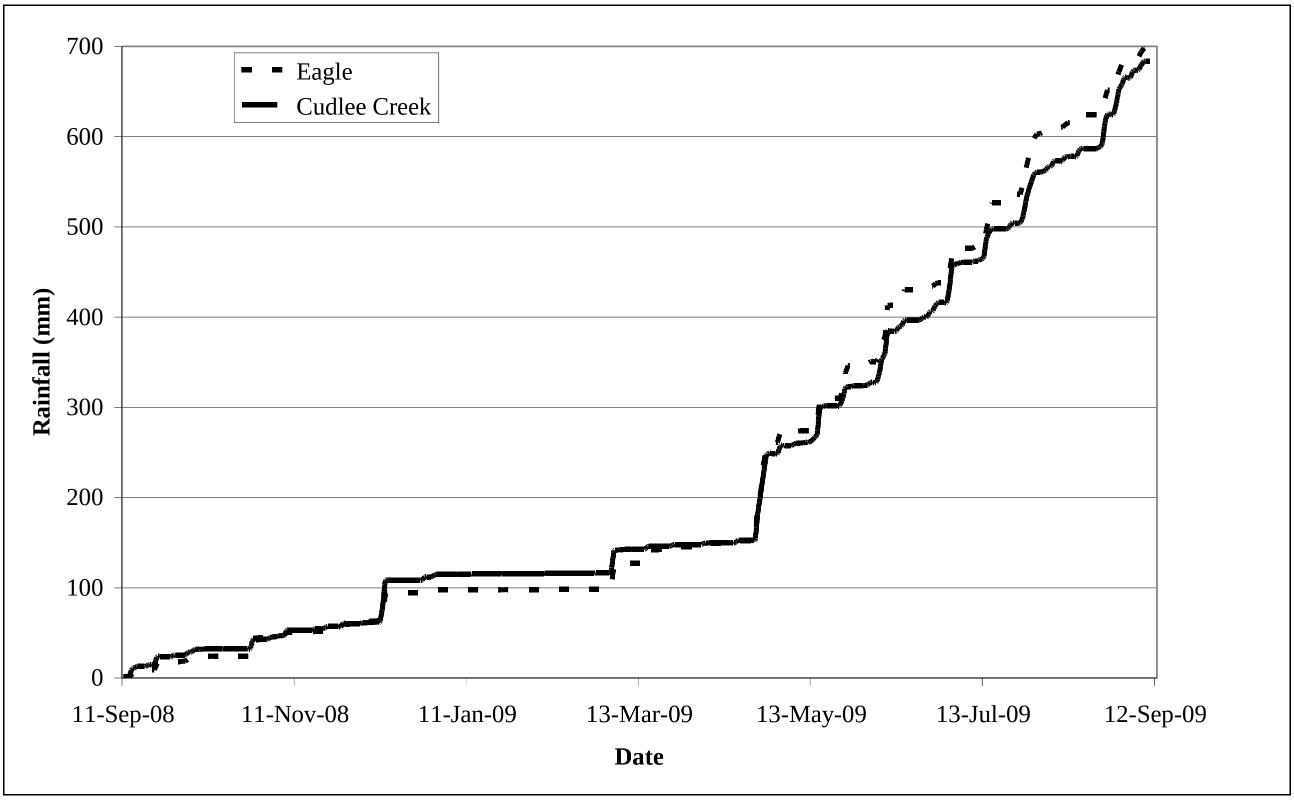

Figure 9 Cumulative rainfall data from the BoM stations nearest the study areas

4 Soil Types

Rudimentary soil type determination was performed at each of the transect points. Determination was effected by placing some clean soil in a straight-sided jar, adding water, shaking thoroughly then allowing the jar to stand for at least five days. The relative amounts of sand, silt and clay are gathered from measurements of the height of each layer.

The soil at *Dynamic Tension* is almost entirely clay (at least 95 per cent) for each of the transect points.

The soil at *Tunnel Vision* is generally loamy with sandy particles on the surface of some transect points (eg 5, 12, 17). The rudimentary method above did not reveal distinct layering.

5 Trail Use

5.1 Cyclist Counters, Deployment and Data Retrieval

A fundamental part of this study is to count the users on each trail. Counters designed to record mountain bike traffic were purchased from TRAFx Research Ltd, Canada and initially deployed on the trails of the study in September 2008.

Two TRAFx counters were deployed on each of the two trails under study. One of the trail pair was deployed at one end with the other deployed at the other end. Two counters are used in an effort to “cross-check” the counts. Mountain bikers using the trails chosen for the study are expected to pass over both counters since there are no easily-usable, mid-trail exit points on either trail. The counters are labeled SCS01, SCS02, SCS03 and SCS04 and deployed as in Table 1.

Table 1 Counter deployment: position

Counter	Trail	Position
SCS01	*Dynamic Tension*	start/upper
SCS02	*Dynamic Tension*	end/lower
SCS03	*Tunnel Vision*	end/upper
SCS04	*Tunnel Vision*	start/lower

The counters SCS01 and SCS02 were deployed at *Dynamic Tension* on 4 September 2008. TRAFx counter SCS01 is at the upper altitude part of the trail and SCS02 is at the lower end. Trail traversal is nominally from the upper to the lower, hence from SCS01 (Start) to SCS02 (End). The direction most often used is probably in the reverse direction since all events held during the study period used the trail from lower to upper. The trail is classed as “Beginner” and has no preferred direction indicated on the trail network map.

The counters SCS03 and SCS04 were deployed at *Tunnel Vision* on 1 September 2008. TRAFx counter SCS04 is at the lower altitude part of the trail and SCS03 is at the upper end. The direction of travel is nominally from the lower to the upper hence from SCS04 (Start) to SCS03 (End). *Tunnel Vision* is an ‘Intermediate’ level trail (level 2 on the four-level scale used in South Australia. Level 1 is the easiest) and has a preferred direction from the lower to the upper end.

Table 2 Counter deployment and data retrieval log

Date	Trail	Comment
1 Sep 08	*Tunnel Vision*	Deployed with standard settings
4 Sep 08	*Dynamic Tension*	Deployed with standard settings
17 Oct 08	*Tunnel Vision*	Retrieval of data. Reset clock times for Daylight Saving Time
19 Oct 08	*Dynamic Tension*	Retrieval of data. Reset clock times for Daylight Saving Time
6 Nov 08	*Tunnel Vision*	Retrieval of data
13 Nov 08	*Dynamic Tension*	Retrieval of data
15 Dec 08	*Dynamic Tension*	Retrieval of data
18 Dec 08	*Tunnel Vision*	Retrieval of data
12 Mar 09	*Dynamic Tension*	Retrieval of data
20 Mar 09	*Tunnel Vision*	Retrieval of data
18 Jun 09	*Dynamic Tension*	Retrieval of data. Reset clock times from Daylight Saving Time
16 Jul 09	*Tunnel Vision*	Retrieval of data. Reset clock times from Daylight Saving Time
11 Sep 09	*Dynamic Tension*	Retrieval of data
18 Sep 09	*Tunnel Vision*	Retrieval of data

Data were retrieved from the SCS counters of *Dynamic Tension* in October, November and December 2008, and March, June and September 2009.

Data were retrieved from the *Tunnel Vision* counters in October, November and December 2008, and March, July and September 2009. The counter SCS03 recorded data from March through to 14 June when either the batteries of the counter failed or were failing to make sufficiently good electrical contact.

The dates of deployment and data retrieval are shown in Table 2. Figure 10 shows one of the counters being deployed at *Dynamic Tension* in March 2009. Note the several levels of sealed plastic protection necessary to prevent water affecting the electronics of the counter.

Figure 10 TRAFx mountain bike counter deployment (*Dynamic Tension*, March 2009)

5.2 Counter Parameter Settings and Records

5.2.1 Counter Calibration

The counters are shipped with a standard setting for two parameters that have an effect on the sensitivity and therefore accuracy of the counter to record the passing of mountain bikes. Calibration of the counters was performed for each set of counters on a number of occasions. This calibration process, the counts recorded and the method for estimating total user counts are detailed in *Appendix A: MTB User Counts – TRAFx Counter Calibration and Records*. The parameter settings were adjusted in an effort to improve the counters sufficiently to enable a reasonable approximation of the number of users riding each trail.

5.2.2 Counter Accuracy

The variations of accuracy of the two counters deployed at *Dynamic Tension* are given in Table 3. The counter SCS02 has a smaller range of variation and is therefore used to estimate daily use for the trail.

Table 3 Low, mean and high accuracy percentages of SCS01 and SCS02

	Percentage		
Counter	**Low**	**Mean**	**High**
SCS01	59	69	100
SCS02	85	89	94

Table 4 Low, mean and high accuracy percentages of SCS03 and SCS04

	Percentage		
Counter	**Low**	**Mean**	**High**
SCS03	68	72	100
SCS04	91	94	100

The variations of accuracy of the two counters deployed at *Tunnel Vision* are given in Table 4. The counter SCS04 has a smaller range of variation and is therefore used to estimate daily use for the trail when it recorded usable data. From 17 October to 6 November SCS04 recorded unusable data so SCS03 is used to estimate daily use for *Tunnel Vision* over this period.

5.3 Counts and Events

5.3.1 Method of Calculation

Estimates of use from each counter can be given as a range based on the number of riders recorded multiplied by factors derived from the overall accuracy percentage calculated from the calibration efforts reported in *Appendix A: MTB User Counts – TRAFx Counter Calibration and Records*. The number of riders recorded is a single number for a given counter during a given recording period. The percentage accuracy for the period is calculated using the aggregated calibration events for that period. The overall accuracy percentage is a range from the lowest to the highest with the mean somewhere in the middle. These three numbers are used to produce the range of the estimates of use for a particular counter during a recording period.

The recorded number of riders is multiplied by a factor which is the reciprocal of the accuracy percentage. As examples, if the number of riders recorded over a recording period is 2,400: with an accuracy of 50 per cent then the estimated number of users is 4,800; if the accuracy is 80 per cent then the estimated number of users is 3,000. The resulting numbers for the recording period are then divided by the number of days in the recording period to give estimates for daily use. Note that these are rounded to whole numbers – the accuracy of the counters does not warrant implying greater precision and even using whole numbers is outside the range of scientific accuracy.

Note that the accuracy percentage used is derived from all of the calibration efforts for that counter.

The total use estimates are rounded in the tables below to the nearest ten, and hence where the accuracy is 100 per cent, the low estimate of use can sometimes be less than the number of records.

5.3.2 Best Estimates of Use

The best mean estimates of daily use of *Dynamic Tension* are given in Table 5 and the estimates for *Tunnel Vision* are given in Table 6.

The variation in accuracy of counter SCS02 at *Dynamic Tension* (85 to 94 per cent) is small enough that coupled with the relatively low number of counts means that the high and low estimates are fractional and therefore no range of use variation is given here (see Appendix A for details and a description of the variability in accuracy between the counters).

Table 5 Best estimates of daily use on *Dynamic Tension* (from SCS02)

Recording Period			Daily
#	**Begin**	**End**	**Users**
1	4 September 2008	19 October 2008	12
2	19 October 2008	13 November 2008	8
3	13 November 2008	15 December 2008	11
4	15 December 2008	12 March 2009	9
5	12 March 2009	18 June 2009	26
6	18 June 2009	11 September 2009	7

Table 6 Best estimates of daily use on *Tunnel Vision* (from SCS04 and SCS03)

Recording Period				Daily
#	Begin	End	Counter	Users
1	1 September 2008	17 October 2008	SCS04	30
2	17 October 2008	6 November 2008	SCS03	360
3	6 November 2008	18 December 2008	SCS04	43
4	18 December 2008	20 March 2009	SCS04	27
5	20 March 2009	16 July 2009	SCS04	26
6	16 July 2009	18 September 2009	SCS04	20

SCS04 recorded unusable data from 17 October to 6 November so the data from SCS03 is used for the estimate.

5.3.3 Event Record

The date, trail used and event description of each of the mountain bike events that utilized either *Dynamic Tension* or *Tunnel Vision* during the course of the study are given in Table 7. The organization responsible for each event is given as a footnote to the table.

By far the most concentrated use of either trail occurred on *Tunnel Vision* during the MTBA Australian MTB Series of 1-2 November 2008. During the counting period of 17 October to 6 November, daily use was estimated at 360 riders per day. This event attracted many riders from interstate and these contributed to the trail being used for practice for several days prior to the competition.

Table 7 MTB event calendar for the study period

Date	Day	Trail	Event
14 September 2008	Sunday	*Dynamic Tension*	[1] Foxy 1000
21 September 2008	Sunday	*Dynamic Tension*	[2] Ego Trip
1-2 November 2008	Saturday/Sunday	*Tunnel Vision*	[3] Australian MTB Series
14 December 2008	Sunday	*Tunnel Vision*	[1] Summer Series race
29 March 2009	Sunday	*Tunnel Vision*	[1] Winter Series race
5 April 2009	Sunday	*Tunnel Vision*	[1] 8-hour race
2-3 May 2009	Saturday/Sunday	*Dynamic Tension*	[2] Dirty Weekend 24-hour event
26 July 2009	Sunday	*Dynamic Tension*	[1] Winter Series race

1. Adelaide Mountain Bike Club.
2. Bicycle SA.
3. Adelaide Mountain Bike Club and Inside Line Downhill Mountain Bike Club with Mountain Bike Australia.

The second most concentrated use of either trail was also on *Tunnel Vision* in the month before, during and for a few days after the Summer Series race held by the Adelaide Mountain Bike Club. During this period an estimated 43 riders per day used the trail. The great majority of the riders were local.

The Dirty Weekend 24-hour event held at Cudlee Creek on 2-3 May 2009 used the *Dynamic Tension* trail. This event attracted some interstate visitors. Over the counting period encompassing the event (12 March to 18 June) 26 riders used the trail daily.

5.4 Summary

The estimated use (without the peaks caused by large events) of *Dynamic Tension* is 8 to 12 riders per day and that of *Tunnel Vision* is 25 to 30 per day. The overall use estimates for the full year and including the large use for events is 45 per day on *Tunnel Vision* and 14 per day on *Dynamic Tension.*

6 Transect Point Topography and Characteristics

The elements of the topography of a transect point are the gradient (or incline) and bearing. Both gradient and bearing apply to the trail itself, the sideslope and the fall line. The elements are described in the following sections along with explanations of how they are measured.

6.1 Trail Gradient

The trail gradients (inclines) are measured as you look away from the transect point in the indicated direction; ie from Start to End (from transect point #1 to transect point #20) or vice versa. A gradient is measured from the centre of the used tread to the point nearest the transect at which there is a discernible change in gradient. This point should be at most 10 m from the transect and in a direct line along the trail. If the transect point is on a bend then the distance to the measuring point may be quite short or could incorporate some of the bend. The gradient is measured between centres of the used tread. The used tread is where at least 95 per cent of riders travel. The point to which the gradient is measured could be at a decrease or an increase in gradient or a grade reversal. The important thing is that from the transect to the chosen point, there is a straight or nearly straight line along the trail. The gradient is measured in both directions. Measurement is given in the usual units of 'per cent'.

When leaving the transect, if the trail rises, then the gradient will be positive, if the trail falls it will be negative. The distance between the transect and the measuring point is recorded. Additionally, the distance to the trail upslope grade reversal is recorded (ie in the positive gradient direction). Note that this may often be further past the point to which the trail gradient is measured. This is recorded to give an indication of the total area of trail (distance multiplied by the full tread width) that could conceivably catch water that may cause erosion of the trail. There is no need to record the distance to the trail downslope grade reversal.

6.2 Trail Bearing

The trail bearings (angles) are measured in degrees with respect to magnetic north and recorded from the transect to the measuring point where the trail gradient changes as this is a straight or nearly straight line along the trail. The trail bearing is measured in both directions. If the transect point is on a straight section of trail, the two bearings are expected to be 180º apart. If the transect point is on a bend, the bearing from Start to End and the bearing from End to Start will not be 180º apart.

6.3 Sideslope Gradient

The sideslopes are on a line through the reference pegs and hence are perpendicular to the trail. A sideslope gradient is measured on the sideslope line with reference to the point that is off the trail and is on 'natural' ground. That is, the reference point is as close to the trail as possible and on ground that has not been disturbed in the building of the trail. This point is likely to be close to the reference peg. Both the upslope and the downslope sideslopes are recorded and are measured from points on the appropriate sides of the trail. The upslope sideslope gradient will be positive as the gradient is recorded with the view referenced from the trail. The downslope sideslope gradient is therefore always negative.

6.4 Sideslope Bearing

The sideslope bearings (angles) are measured with respect to magnetic north and recorded in both directions looking from the middle of the trail along the sideslope line that passes through the reference pegs. The bearing for each of upslope and downslope is recorded as referenced from the trail and, within the tolerances of measurement error, should be 180º apart.

6.5 Fall Line Gradient

The fall line follows the line of flow of water down a slope. Like the sideslope gradient, the fall line gradient is recorded with reference to the point that is next to the trail, on the line of the transect and is on ‘natural’ ground. On the upslope side, the fall line is where water will come from to arrive at the point next to the trail that is on natural ground. On the downslope side, the fall line is the direction water will travel away from the point on the line of the transect next to the trail. The upslope fall line gradient will be positive. The fall line gradient has an absolute value that is at least equal to that of the sideslope gradient. The fall line of a contour trail often coincides with the sideslope.

6.6 Fall Line Bearing

The fall line bearings (angles) are measured with respect to magnetic north and recorded from the same point just off the trail as for the sideslope and fall line gradients.

6.7 Trail to Fall Line Angle

The trail to fall line angle is measured between the trail and the upslope fall line. The value of the trail to fall line angle can give an indication of the potential susceptibility of that part of the trail to erosion from water runoff. Ideally water should spend as little time on the tread of the trail as possible and hence the optimum trail to fall line angle is 90 degrees with the tread constructed with out-slope.

In trail design and construction, there must be a balance between the conflicting aims of the desire for water to traverse the trail as quickly as possible (trail to fall line angle of 90 degrees and a steep out-slope) and the need for the action of the water to be gentle (water to have minimal velocity by dispersing it along the trail and by building a gentle out-slope on the tread). Sustainable trails are constructed with trail to fall line angles as close to 90 degrees as possible at all points, with regular dips and rises to help prevent accumulation of large volumes of moving water, and with out-sloped trail tread. All of these features help drain the water off the trail in the most efficient and effective manner possible.

7 Used Tread Width Changes

The used tread width is that part of the tread in which it is estimated that 95 per cent of riders will travel. Ascertaining the used tread width is in some cases a somewhat subjective exercise but for the most part, the travel line boundaries are reasonably clear to within a centimetre or two across the transect. Evidence for the narrowing of the used tread is the growth of vegetation (usually grasses) further towards the middle of the tread. Part of the study is to see if the used tread widths change markedly over a twelve-month period and if they do, in what manner.

Of the twenty transect points on *Dynamic Tension*, fourteen did not show marked change. All six that changed became narrower; three by ten per cent or less, one by eighteen per cent and the other two by 23 and 29 per cent. The transect point whose used tread width reduced by 29 per cent was affected over the course of the study by the growth of a tree next to the trail. The mean used tread widths at the twenty transect points reduced from 51 to 48 cm.

Of the twenty transect points on *Tunnel Vision*, fourteen did not show marked change. Of the six that changed noticeably, four became narrower and two became wider. Of the four that became narrower, two were by ten per cent or less, one by eleven per cent and the other by 29 per cent.

Of the two that became wider, one was by thirteen per cent from 37 to 42 cm and the other by 38 per cent from 29 to 40 cm. The former of these two became wider on the downside of the used tread. It should be noted here that the surface at this transect point is not a natural surface but is packed stone and the wider tread being used is still totally on this hard-wearing surface. It is very unlikely that the used tread will become wider as the transect point is bordered by bushes close to the trail and observations of riders passing the point during a race showed that the vegetation is not disturbed except for slight movement caused by rider-created wind. The used tread width change of 38 per cent is occurring on both the upside and downside at the transect point and the entire width of the new tread is within the boundaries of the tread as it was built. There is no evidence that riders are veering off the trail at this point and the used tread width change indicates that more riders are comfortable on a range of parts of the trail rather than the change occurring due to speed or preliminary alignment by the rider to the next downtrail obstacle/feature/corner.

The mean used tread widths at the twenty transect points remained the same at 43 cm.

In conclusion, 70 per cent of the transect points show no change in used tread width, 25 per cent have become narrower and 5 per cent have become wider but none are wider than the surface of the trail as built. The mean used tread width over the 40 transect points reduced from 47 to 45 cm.

8 *Tunnel Vision* Transect Point Analysis

8.1 TV-1

This transect point shows no significant soil movement. The values of the mean change in profile area are within the variation to be expected from the measuring technique. There is no evidence of soil movement from the upslope bench or from the immediate vicinity of the trail itself (no channels from erosion or tyre marks); the photographic record does not indicate loss. The surface is hard-packed small stones and soil. There has been a widening of the used tread of thirteen per cent but not to an area off the full tread. The transect point is on a part of the trail with a gradient change – a rise of 8° on one side and a fall of -1° the other – and has the optimum trail to fall line angle of 90°. The tread has outslope.

Conclusion: no change.

8.2 TV-2

This transect point is similar to TV-1 and shows no significant soil movement. The values of the mean change in profile area are within the variation to be expected from the measuring technique (the December 2008 measurements were discarded as the horizontal bar moved during the measuring process and this was only picked up during analysis). There is no evidence of soil movement from the upslope bench or from the immediate vicinity of the trail itself (no channels from erosion or tyre marks); the photographic record does not indicate loss. The surface is hard-packed small stones and soil. There has been a widening of the used tread of 38 per cent but not to an area off the full tread. The transect point is at the low point of a grade reversal and has the optimum trail to fall line angle of 90°. The tread has outslope.

Conclusion: no change.

8.3 TV-3

This transect point is on the exit of a downhill s-bend. The values of the mean change in profile area are within the variation to be expected from the measuring technique. There is some evidence of a small amount of soil movement from the upside bench across the trail at the transect point: the tread has outslope. There are no channels from erosion or tyres. The surface is hard soil with some embedded small stones. The used tread has narrowed over the year. The transect point is on a slope of about 8 per cent and has the near-optimum trail to fall line angle of 85°.

Conclusion: minor, insignificant change.

Figure 11 Two views of TV-3: September 2008 and September 2009. NB these two photos were taken in slightly different places and at different heights.

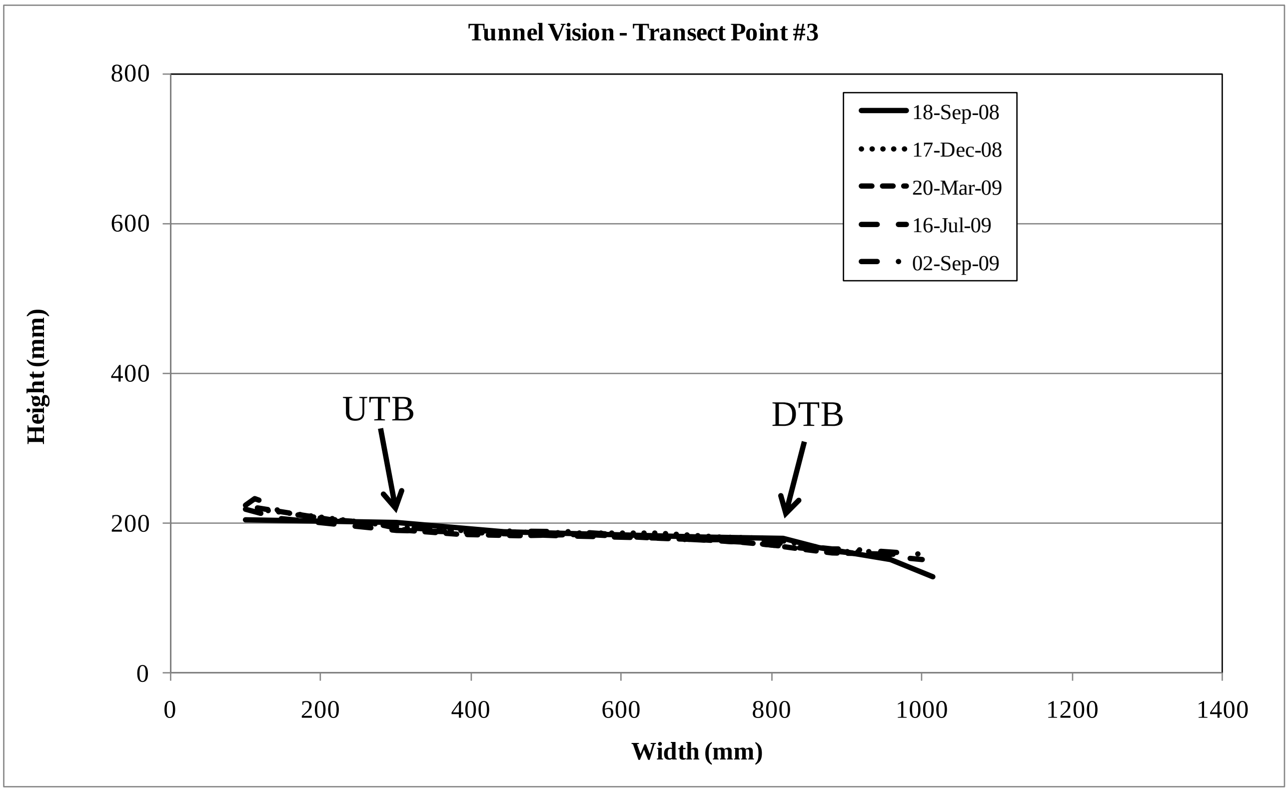

Figure 12 TV-3 transect profile changes showing minor but insignificant changes on the downslope side

8.4 TV-4

This transect point is on a straight section of trail with a rising gradient. This transect is one of the more difficult transects to measure as it has (a) a steep bank on the upside of the tread and within the measuring limit of the transect; and (b) a small, exposed tree root diagonally across the transect. Both of these elements are the most difficult from which to obtain repeatedly similar measures. The surface is compact soil with some vegetation, small stones and a few very small twigs. There has been no change in the width of the used tread. The mean change in profile area values are within expected variation and the photographic record shows no significant wear. The transect point is on a slope of about 11 per cent and has the near-optimum trail to fall line angle of 85°. The profile of the tread is concave with a ridge of soil and vegetation on the downside.

Conclusion: no change.

8.5 TV-5

This transect point has a surface of compact soil with a light covering of loose small stones. No gouging or incisions are evident from the profile graphs, photographs or from visual inspection. The profile graphs are of a consistent shape. The point is situated on a slight bend with a small gradient. The used tread narrowed by 10 per cent over the year. The profile of the tread is concave with a ridge of soil and vegetation on the downside. The mean change in profile area values are within expected variation and the photographic record shows no significant wear. The trail to fall line angle is 80°.

Conclusion: no change.

8.6 TV-6

This transect point is on a bend and at the foot of a grade reversal with slopes of around 6 per cent either side. The surface is hard soil with a light covering of loose small stones. No gouging or incisions are evident. The profile graphs have a consistent shape. The tread profile is almost straight and has outslope. The used tread width has not changed. The trail to fall line angle is 85°. The mean change in profile area values are within expected variation and the photographic record shows no significant wear.

Conclusion: no change.

8.7 TV-7

This transect point is on a slight curve on a gradient of about 5 per cent with the upslope grade reversal about 25 m towards the end of the trail. The surface is a layer of sand over hard soil. The profile graphs have a consistent shape despite the sand layer and the mean change in profile area values are within expected variation. The tread has outslope and the used tread width has not changed. The trail to fall line angle is 85°.

Conclusion: no change.

8.8 TV-8

This transect point has two distinct lives over the course of the study. The first was over the first three studies and by coincidence the trail at the transect point was altered on the day of the third survey about one hour after it was measured for the study. The new transect profile was measured after the alteration and hence the second life spanned the last three surveys. The changes to the transect profile for the first life can be analysed by viewing the section of trail as having ‘bedded in’ whereas the changes over the second life are very much due to the trail bedding in.

The transect point for the first three surveys was about 50 cm before a narrow part of the trail anchored on one side by a rock and on the other by a tree stump and with a grade of about 20 per cent. It was difficult to ride for riders with minimal fitness and skill levels as the approach to the constraint was uphill (about eight per cent) through a narrow defile between two trees only about three metres beforehand. The surface was packed earth and ash and the profile looks like a widely-splayed V. The profile graphs have a consistent shape and the mean change in profile area values are within expected variation. Despite the narrowness of the constraining point, the used tread width increased by 14 per cent from September 2008 to March 2009. The trail to fall line angle is 90°.

Conclusion: no change (see Figure 14).

The alteration to the trail adjacent to the transect point was to remove the rock and hence widen the trail. The transect profiles over the surveys of March, July and September 2009 showed a compression or loss of soil consistent with the surface bedding in and the profile is still concave. The used tread width did not change over this period and the mean changes in profile area tend to indicate the tread has little more bedding in to do. The trail to fall line angle is 90°. The approach to the transect point for a rider is the same as before. The approach to the transect point is still uphill and between the two trees.

Conclusion: minor change due to the tread bedding in after alterations (see Figure 15).

Figure 13 TV-8 before (March 2009) and after (September 2009) the removal of the rock and the reshaping work of 26 March 2009

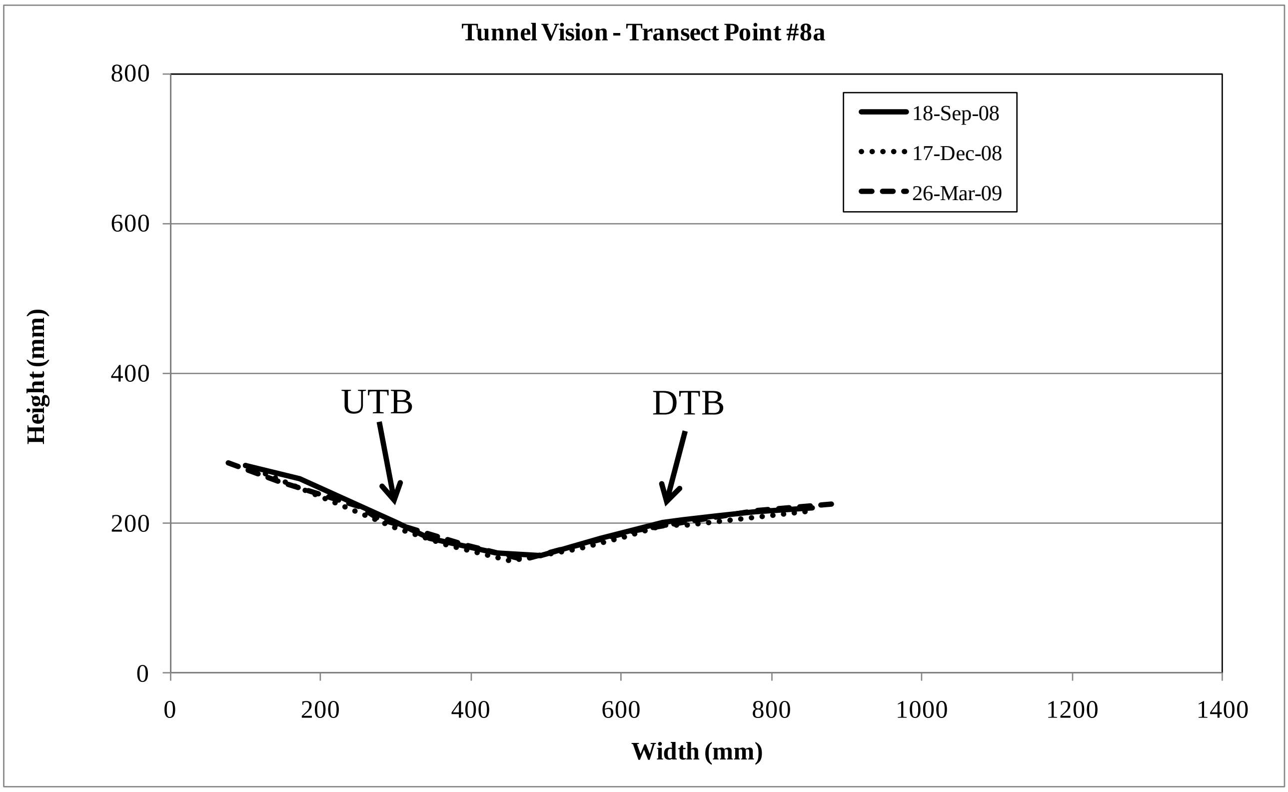

Figure 14 TV-8 before the reshaping work on 26 March 2009

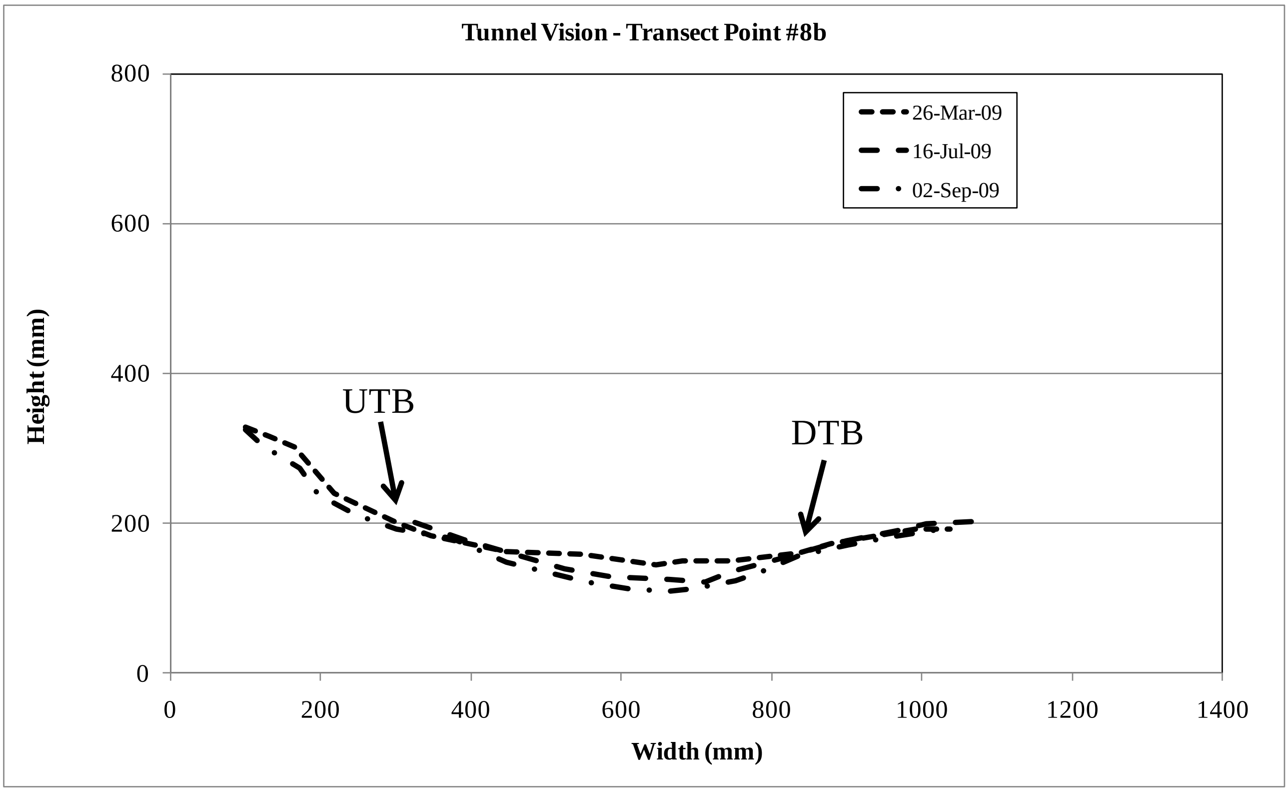

Figure 15 TV-8 after the reshaping work of 26 March 2009

8.9 TV-9

This transect point is on a section of the trail characterised by rocks embedded in soil and bounded on the left by a small tree: the used tread width has not changed. The transect profiles reflect the rocks in the trail but their shapes are consistent over the five surveys and the mean change in profile area values are within expected variation. The gradient is about eight per cent and the grade reversal is about 10 m further along the trail. The tread is outsloped discounting the rocks. The trail to fall line angle is 90°.

Conclusion: no change.

8.10 TV-10

The transect point is on a short (about 17 m) section of trail with the upslope on the trail grade reversal distance of about 10 metres. The section of trail is characterised by rocks embedded in soil. The transect point is at the steepest part of this section at about twenty per cent and the trail tread for about two metres upslope and about three downslope does not have outslope. The transect point is next to a tree on the left of the trail and with a bank on the right constrains riders and thus has resulted in no change to the used tread width (about 36.5 cm). The trail for about ten metres back from and about thirty metres past this transect point is constrained by an area of significant vegetation on the nominal left (hill downslope) side, thus its position has resulted in a relatively low value of trail to fall line angle of 50° compared with the desired 90°. The trail to fall line angle of 50° coupled with a sizable catchment area populated by grasses on the sideslope hillside to the right of the transect point could well induce water run-off to proceed for some distance along the trail rather than crossing the trail with minimal erosive effect.

The trail profiles show some soil loss in the used tread (see Figure 17). This is confirmed by inspection of the photographs and the mean change in profile area values suggest this loss occurred mainly between the March and July surveys (47 per cent of the rainfall that fell during the study period occurred between the March and July surveys; estimated use during this period is 26 riders per day which is within the range of the estimate of 25 to 30 per day for the whole year – excluding event traffic – and is about 18 per cent of the total) with no change from July to the September survey. The soil loss across the transect for a nominal 1 cm wide strip could easily fit onto a small garden trowel and there was no evidence of deep gouging (Figure 16).

Conclusion: significant change (loss).

Figure 16 TV-10 in September 2008 and September 2009 showing the effects of soil movement

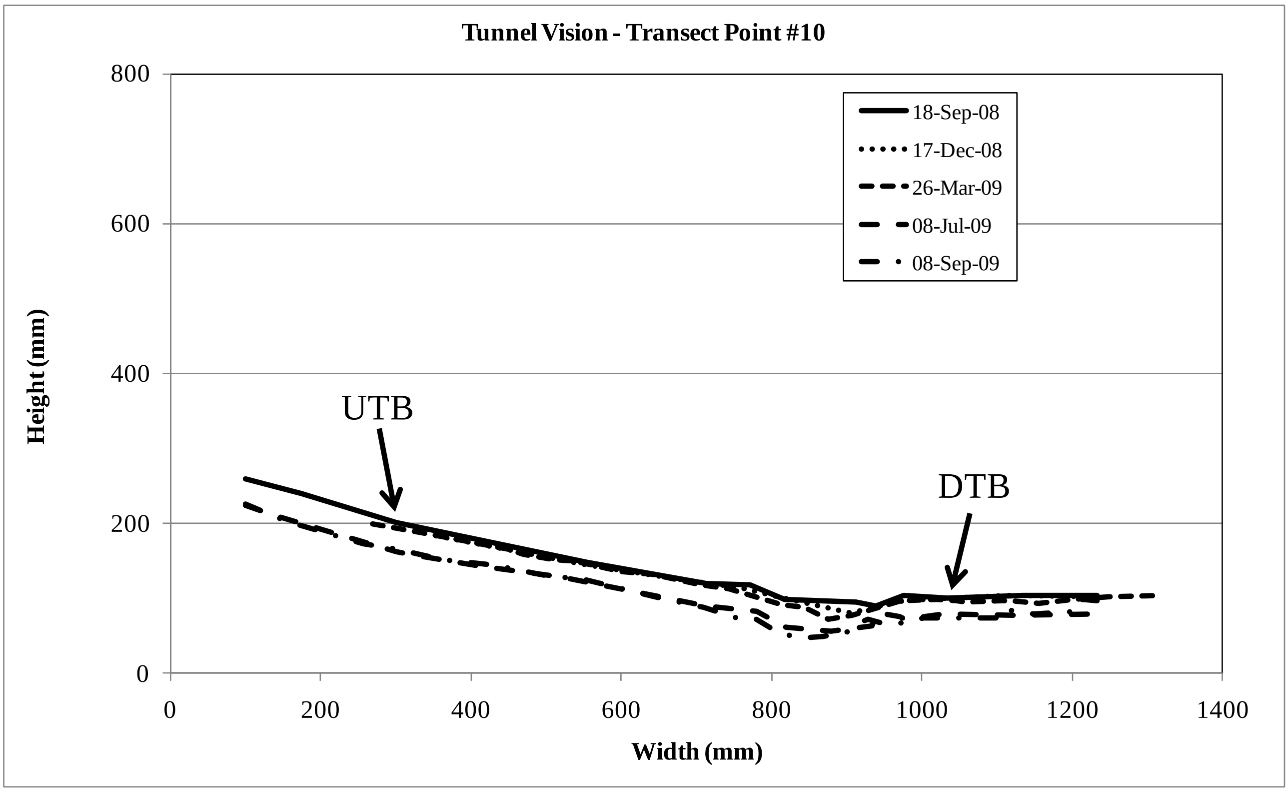

Figure 17 TV-10 profiles

8.11 TV-11

This transect point is at the nadir of a grade reversal with trail gradients of about 5 per cent either side. The profile is slightly concave. The surface is hard-packed earth with some loose small stones. The used tread width has not changed. The transect profiles graphs have a consistent shape and the mean change in profile area values are within expected variation. The trail to fall line angle is 90°.

Conclusion: no change.

8.12 TV-12

This transect point is at the exit to a right-hand corner one metre past a rock-armoured cross-trail drain which acts as the lower trail gradient grade reversal. The trail gradients from the drain is thirteen per cent. This flattens to a slight one per cent at the transect point with the upper trail grade reversal two metres further on. The surface is hard soil with embedded stones. The used tread width has not changed. The tread has outslope. The trail to fall line angle is 90°. The transect profiles graphs have a consistent shape and the mean change in profile area values are well within expected variation.

Conclusion: no change.

8.13 TV-13

This transect point is on a straight section of rising trail (gradient about 7 per cent). The surface is of packed soil with some embedded small stones, some loose small stones and a sandy layer with leaf litter and a few small twigs. The sand layer is enough to show evidence of the passage of bicycles though there are no incisions into the tread. The upper trail gradient grade reversal is four metres along the trail. The graph of the transect profiles shows a small, insignificant soil gain and this is reflected in the mean change in profile area values. The trail to fall line angle is 80°. The tread has outslope and there has been no change in the used tread width.

Conclusion: minor, insignificant change (gain).

8.14 TV-14

The surface of this transect point is similar to that of TV-13: packed soil with some embedded small stones, some loose small stones and a sandy layer with leaf litter and a few small twigs. The transect point is on a slightly curved section of rising trail (gradient about 6 per cent) with the grade reversal two metres along the trail. The tread has outslope and the used tread width has narrowed by 29 per cent. The transect profiles graphs show a small loss of soil and this is reflected in the mean change in profile area values over both the used tread and the measuring widths. The trail to fall line angle is 80°.

Conclusion: minor, insignificant change (loss).

8.15 TV-15

The surface of this transect point is a reasonably thick layer of sand on hard soil. The transect point is on a descending part of the trail (gradient about -6 per cent) and would experience relatively high speeds of riders. The transect profiles graph shows a small loss of soil near the outside of the tread. The tread has outslope and the used tread has narrowed by about seven per cent. The trail to fall line angle is 75°. The upper trail grade reversal is 22 metres back along the trail from the transect point. There are no gouging or incision marks at the transect point.

Conclusion: minor, insignificant change (loss).

8.16 TV-16

This transect point is on a gentle rising (three per cent trail gradient) curve. Its surface is of packed soil. The tread has outslope and the used tread width has not changed. The transect profiles graphs have a consistent shape and the mean change in profile area values are within expected variation. The trail to fall line angle is 85°.

Conclusion: no change.

8.17 TV-17

This transect point is on a straight section of descending (gradient about 7 per cent) trail. The transect profile is of a splayed V. The trail surface is packed soil with loosed stones, some leaf litter, some small twigs and a thin layer of sandy soil. The mean change values indicate some soil loss between the March and July surveys. The used tread width has not changed. The trail to fall line angle is 70°.

Conclusion: minor, insignificant change (loss).

8.18 TV-18

This transect point is on a slight left-hand rising curve (gradient about 3 per cent) of the trail. The transect profiles graphs are consistent and the mean change values show minimal variation; well within expected variation. The surface is packed soil with some leaf litter, some small twigs and a thin layer of sandy soil. The used tread width has not changed. The trail to fall line angle is 80°

Conclusion: no change.

8.19 TV-19

This transect point is on the edge of a plateau between two slight rises. The trail gradient to the transect point is about seven per cent and away about 2 per cent for about three metres before a climbing turn. The surface is soil with leaf litter and small twigs (Figure 18). The transect profiles are consistent (Figure 19), nearly straight and the tread has outslope. The used tread width has not changed. The trail to fall line angle is 80°. The mean change values are minimal.

Conclusion: no change.

Figure 18 TV-19 in September 2008 and the surface in September 2009

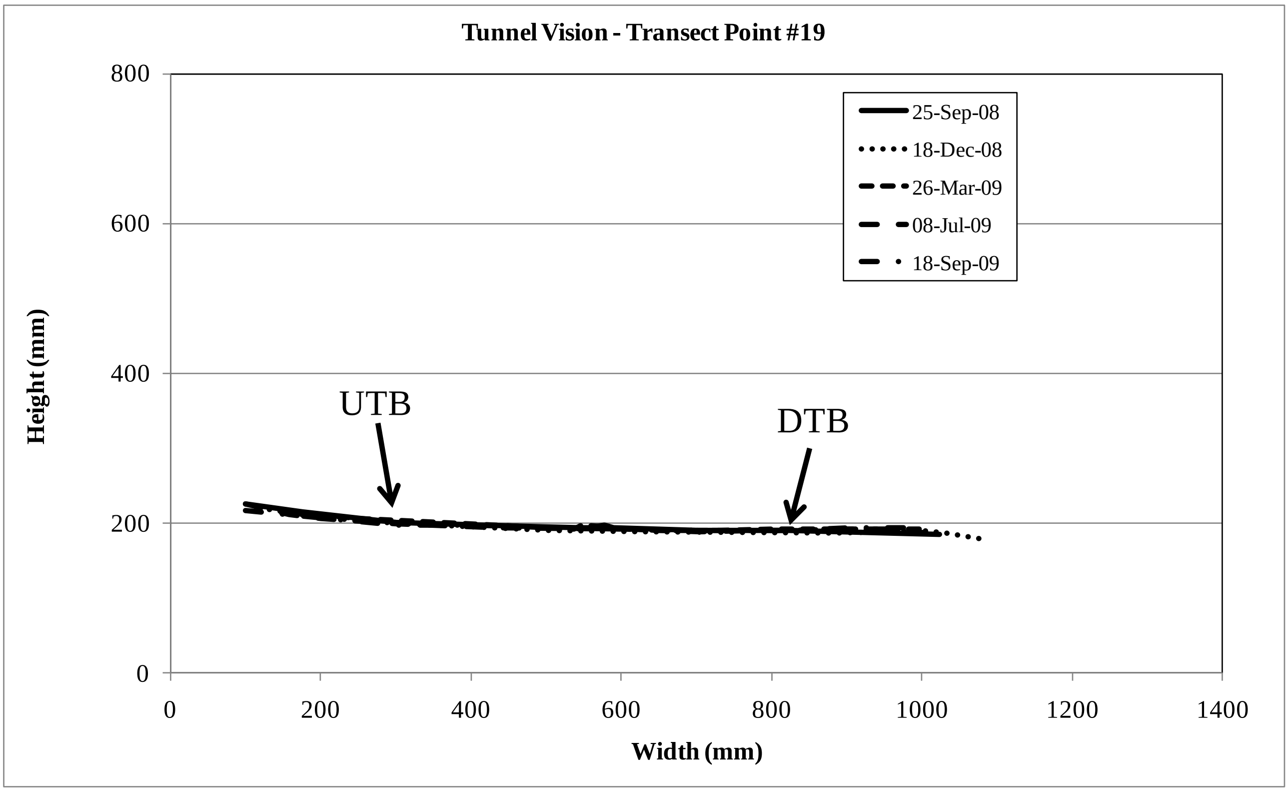

Figure 19 TV-19 profiles

8.20 TV-20

This transect point is on a straight section of the trail with a gradient of about 3 per cent. The trail to fall line angle is 75°. The surface is compact, sandy soil with loose small stones towards the outside of the tread which is slightly concave. There has been no change to the used tread width. The mean change values are minimal and the transect profiles are consistent.

Conclusion: no change.

8.21 *Tunnel Vision* Summary

Of the 20 transect points on *Tunnel Vision*, thirteen showed no change discernible using the measurement and observation techniques of this study. Six showed minor, insignificant change. One showed significant change between the March and July 2009 surveys (the soil loss across a 1 cm strip of the transect could easily fit onto a small garden trowel; 47 per cent of the recorded rainfall during the study fell between the March and July 2009 surveys; estimated use during this period was 26 riders per day compared with 25 – 30 as the estimated range excluding events throughout the study period) with no further change up to the September survey.

9 *Dynamic Tension* Transect Point Analysis

9.1 DT-1

Transect point #1 showed significant change. The point is on a descending section of the trail (12 per cent) on a slight curve. It is about five metres short of the entrance to a descending left-hand turn and as such is a braking area for riders travelling in the nominated direction for this study. At least two of the MTB events that used the trail in the study period used the trail in the reverse of the nominated direction: the transect point was on a climbing section of the trail for the *Foxy 1000* (October 2008) and the *Dirty Weekend* (May 2009) 24-hour event. The *Foxy 1000* accounted for approximately 10 per cent of the total use estimated over the study period, and the *Dirty Weekend* accounted for approximately 50 per cent of use (about 2,200 passes). The trail was dry at the commencement of the *Dirty Weekend* and no rain fell during the event.

The trail to fall line angle is small at about 55° and the distance to the grade reversal when climbing on the trail away from the transect point (the uptrail grade reversal) is about 8 metres. At the first survey in September 2008 there was a noticeable channel where soil loss from the used tread had occurred (Figure 20). This deepened and widened slightly between September and December 2008 during which time the trail experienced about 12 per cent of the rainfall and its mean use per day was 10 to 11 riders or about 22 per cent of total estimated use.

The channel further deepened and widened by March 2009 during which time the trail experienced approximately 9 per cent of rainfall and about 9 riders per day (about 16 per cent of total use). After experiencing some soil loss in the first half of the study the transect point profile now appears to be stable. There was no discernible change in the profile between March and June 2009. This period included the *Dirty Weekend* event when about 51 per cent of the usage for the study year occurred.

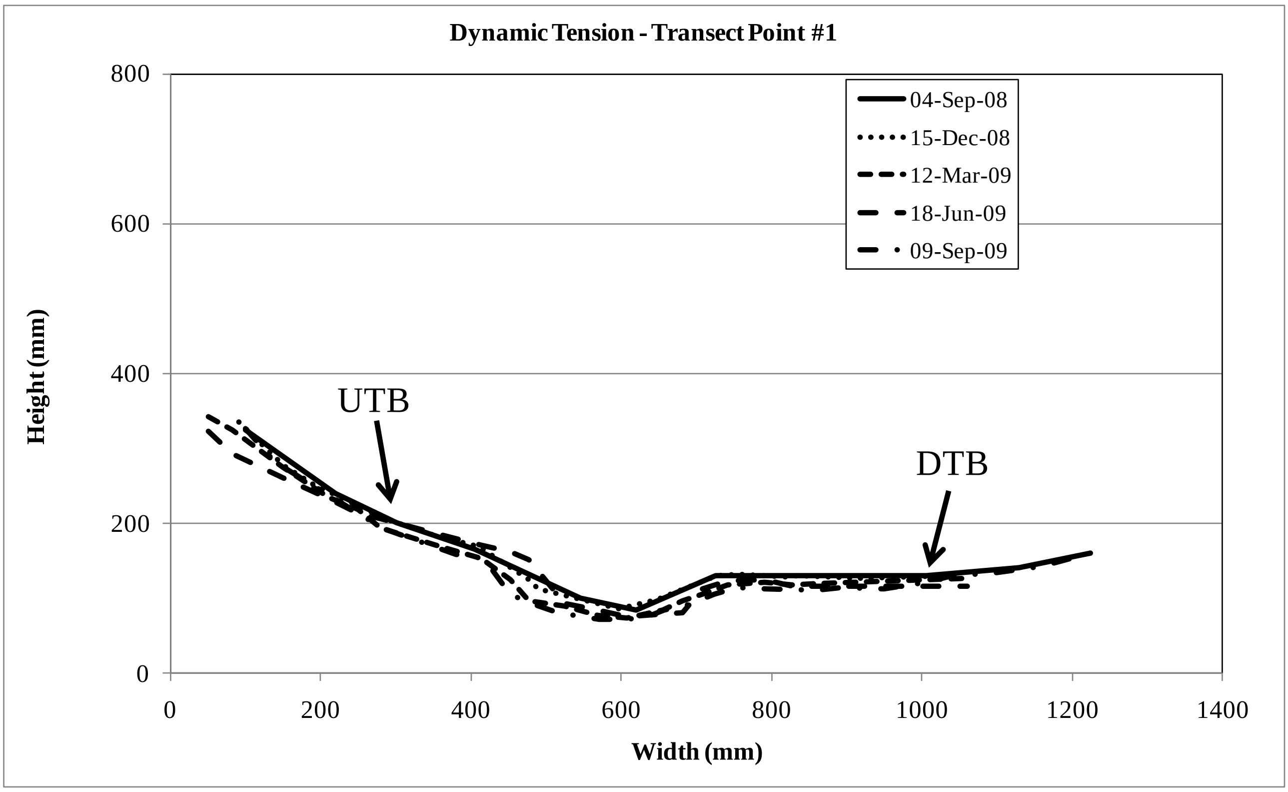

Figure 20 DT-1 transect profiles

Figure 21 ***Dynamic Tension* transect point #1 in September 2008 and September 2009 showing the widening of the riding channel**

Conclusion: significant change (loss).

9.2 DT-2

The transect point is at the start of a straight section of trail about one metre after a low-point grade reversal at the end of a right-hand descending turn. The surface is packed soil with a few embedded small stones. The transect point is at the top of the small rise: hence both trail gradients are negative. The mean change values are minimal and the transect profile graphs are consistent. The tread has slight outslope and the used tread width has narrowed by about 8 per cent over the year. The trail to fall line angle is about 75°.

Conclusion: no change.

9.3 DT-3

This transect point is on the apex of a descending turn, was constructed with a berm and therefore has no outslope. Its gradient is quite steep – as to be expected on the apex of a turn – at 23 per cent. It would be expected to suffer wear through erosion, if anywhere, on the inside of the curve and displacement through use further towards the outside of the curve. The surface is of packed soil with many embedded and many loose pebbles. The transect profile graphs are consistent and the mean change values within expected tolerance. As the transect point is on the apex of the turn connecting two sections of trail that are essentially across the hillside, the trail to fall line angle is very small at about 5°.

Conclusion: no change.

9.4 DT-4

This transect point is at the drain of a low portion of the trail and has experienced some soil gain due to sediment pooling from erosion and wear from above the transect point. The gradient is therefore zero at the transect point itself for a few centimetres and the values given in Appendix B are from a few metres away to give a perspective of the point on the trail. Subsequent measurements should indicate if this soil movement is continuing or if it has stabilized. The surface is silty and may become muddy in the wet and dusty in the dry. The mean change values indicate the movement of soil to the transect as can be seen in the transect profile graphs. The used tread width has not changed. The trail to fall line angle is about 80°.

Conclusion: minor, insignificant change (gain).

9.5 DT-5

This transect point is adjacent to a low-point, grade reversal on a fast, slightly curved section of the trail and has little gradient. The mean change values indicate some soil loss occurred between December 2008 and March 2009 and some soil gain between March and June 2009, though this gain appears to have settled. Overall there has been a slight loss of soil. The surface is packed soil and the tread is concave. The used tread width has not changed. The trail to fall line angle is about 90° and the uptrail grade reversal is 8 metres away.

Conclusion: minor, insignificant change (loss and gain).

9.6 DT-6

This transect point is of packed earth with a few small pebbles and is on the rising side (3 per cent gradient) of a longish curve after a low point grade reversal. No data is available for the September 2008 survey so the December 2008 survey is used as the baseline for comparisons. Mean change values are within expected measurement variation and the transect profile graphs are consistent. The tread is concave and the used tread width has not changed. The trail to fall line angle is about 80° and the uptrail grade reversal distance is about 12 metres.

Conclusion: no change.

9.7 DT-7

This transect point is near a low point of a grade reversal and therefore has a small gradient (one per cent) and has experienced a small amount of soil gain due to sediment pooling from erosion and wear from above the transect point. The mean change values are within expected variation and the transect profile graphs are consistent. The tread is flat and the used tread width has not changed. As the transect point is near a low point, the trail to fall line angle is unusual in that it is more than ninety degrees at about 115°.

Conclusion: minor, insignificant change (gain).

9.8 DT-8

This transect point is on a slight downhill section just before a left-hand turn. The tread is concave, the used tread width has not changed and the surface is packed earth. The mean change values are minimal and the transect profile graphs are consistent. The uptrail grade reversal is 10 m and the trail to fall line angle is about 95°.

Conclusion: no change.

9.9 DT-9

Transect point #9 is the other point that revealed significant change over the course of the study: it exhibited both soil loss and gain. The point is at the foot of a descending, right-hand curve of the trail and is at a drainage point on the turn that leads several metres away into a left-hand descending turn. The trail at the transect point has gradients of 1 and 4 per cent either side. The mean change values and the transect profile graphs indicate soil loss from September to December 2008 (about 12 per cent of rainfall and about 22 per cent of riders over this period) then deposition from June to September 2009 (40 per cent of the rainfall occurred in this period and about 12 per cent of riders) (see Figure 22 for transect profiles and Figure 23 for a snapshot taken in June 2009). These changes resulted in a nett zero change in transect profile area over the study period. The surface is soil with embedded small stones that help secure the soil. The used tread width has not changed and the tread started with slight outslope and is now almost flat from sediment deposition at the drain point. The trail to fall line angle is about 60° and the long side uptrail grade reversal distance is 17 m (in this case towards the start of the trail). The shape of the tread for about 10 m on the uptrail side is concave and this, coupled with the low trail to fall line angle would not allow water to run off the trail but induce it to move down to the transect point. The profile measurements, backed by the photographic record and notes taken during the study show that this water does carry some sediment that is deposited at the drain at the transect point.

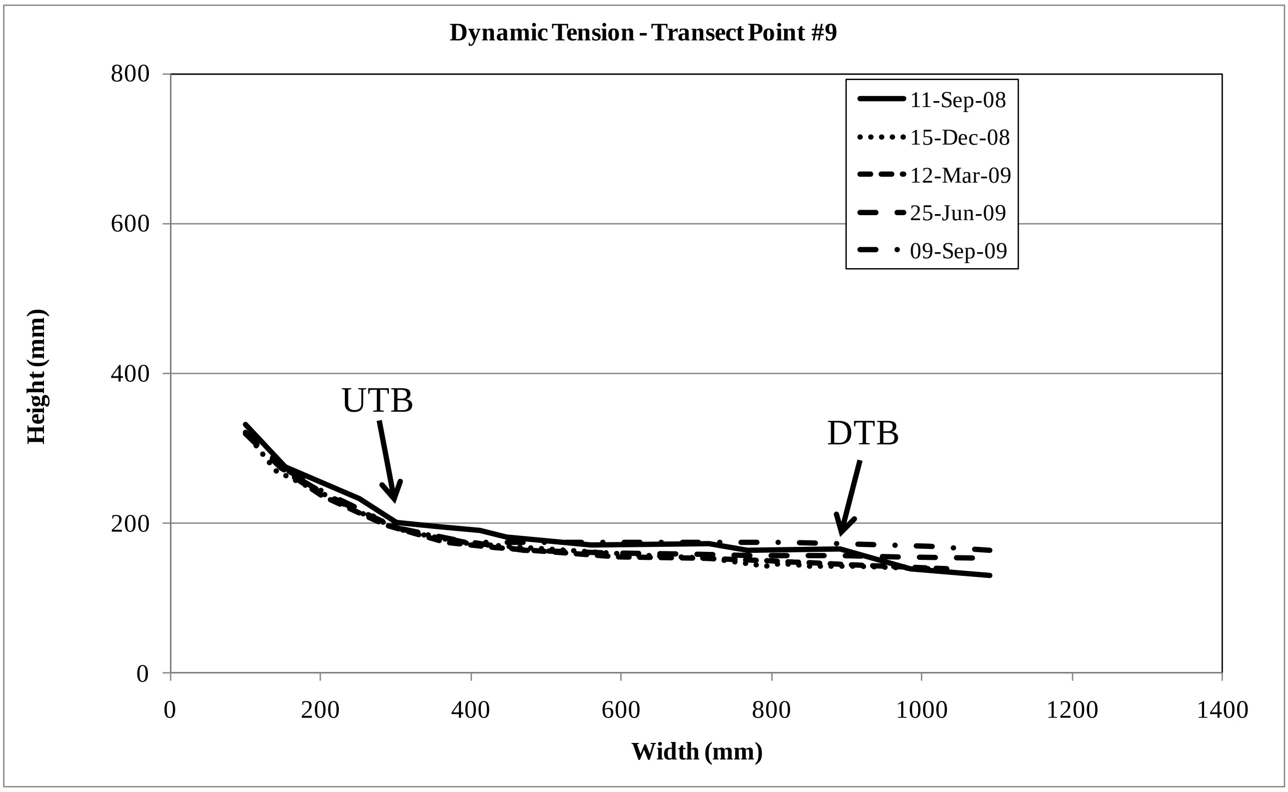

Figure 22 DT-9 profiles

Figure 23 *Dynamic Tension* transect point #9 in June 2009

Conclusion: significant change (loss and gain).

9.10 DT-10

This transect point is at the exit of a right-hand descending turn about one metre before a trail drainage point which is just before a left-hand turn. The gradient is quite steep at 12 per cent for 2 metres of the 10 m to the uptrail grade reversal. The surface is hard soil with many small stones; some embedded and some loose (Figure 24). The mean change values and graphs (Figure 25) indicate some soil loss between September and December 2008 and possibly more loss between March and June 2009. The tread is concave and the used tread width has narrowed by 18 per cent. The trail to fall line angle is 75°.

Conclusion: minor, insignificant change (loss).

Figure 24 DT-10 in December 2008 and September 2009

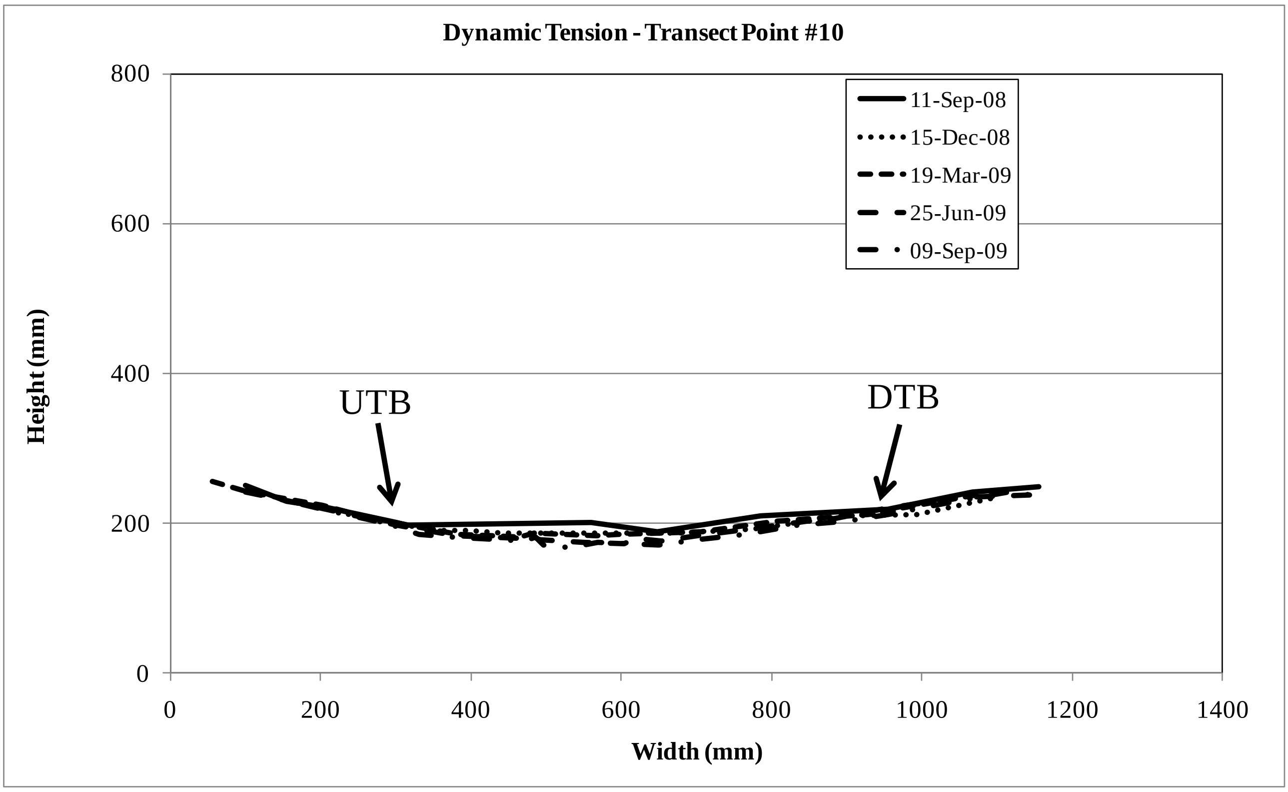

Figure 25 DT-10 profiles showing the soil loss between September and December 2008

9.11 DT-11

This transect point is on a left-hand descending curve. The surface is soil with many embedded and loose small stones. The tread is concave and the used tread width has not changed. The mean change values are within expected measurement variation and the transect profile graphs are consistent. The trail to fall line angle is about 100° and the uptrail grade reversal distance is 4 m.

Conclusion: no change.

9.12 DT-12

This transect point is on a left-hand, fairly steep (10 per cent) descending curve and riders would be travelling at a reasonably fast speed when moving in the nominated forwards direction. The mean change values are within expected measurement variation and the transect profile graphs are consistent. The surface is soil with many embedded and loose small stones that may have helped armour this part of the trail. The tread is concave, is slightly bermed and the used tread width has narrowed by 6 per cent. Uptrail grade reversal distance is lengthy at 15 metres and the trail to fall line angle is a shallow 50°.

Conclusion: no change.

9.13 DT-13

This transect point is on a steeply-ascending (31 per cent) section of the trail. The surface is compact soil with a few embedded and loose small stones that may have helped armour the trail here. The tread is concave and the used tread width has not changed. The mean change values indicate a small soil loss and photographs show stones gathered in the bottom of the used tread between March and September 2009. The transect profile graphs are consistent and there has not been any gouging. The trail to fall line angle is about 60° and the uptrail grade reversal distance is at 6 metres.

Conclusion: minor, insignificant change (loss).

9.14 DT-14

This transect point is on an ascending section of trail (5 per cent) and part of a right-hand curve. The surface is soil with many embedded and loose small stones. The tread is concave and the used tread width has not changed. The mean change values are within expected measurement variation and the transect profile graphs are consistent. The trail to fall line angle is about 78° and the uptrail grade reversal distance is 13 metres.

Conclusion: no change.

9.15 DT-15

This transect point is on a relatively flat section, right-hand curve of the trail. The surface is soil with many embedded and loose small stones. The used tread is concave and its width has not changed. The mean change values indicate there may have been some soil loss but the transect profile graphs are consistent indicating that this is probably not the case. As it is flat, there is no distance to the uptrail grade reversal distance. The trail to fall line angle is a mere 30°.

Conclusion: if any change it is minor and insignificant.

9.16 DT-16

The trail at this transect point is deceptive as the point is in the middle of a section of trail that appears reasonably flat, but isn’t and the point itself is on a section a few metres in length that is steeper (8 per cent) than for several metres either side. The transect point is on a right-hand curve of the trail with the surface comprising hard-packed soil with some embedded small stones. The used tread is concave and its width has narrowed by 10 per cent. The mean change values are minimal and the transect profile graphs are consistent. The distance to the uptrail grade reversal is 4 metres and the trail to fall line angle is about 60°.

Conclusion: no change.

9.17 DT-17

This transect point is on a part of the trail that is a descending left-hand curve with a relatively steep gradient of 20 per cent. The trail to fall line angle is 14° and it is clear that considerable wear and erosion occurred before this study commenced (see Figure 26 for a visual indication). Perhaps unexpectedly, over the course of the study little change occurred (profiles are reasonably consistent – see Figure 27 – and the mean change values are within expected variation) indicating the trail at this transect point is holding up to wear and weather. The distance to the uptrail grade reversal is 9 metres. The surface is packed soil with embedded and loose small stones. The tread at this transect point is the most concave of the *Dynamic Tension* points. The used tread width has not changed.

Conclusion: no change.

Figure 26 DT-17 in August 2008 and September 2009 showing no change despite the minimal trail to fall line angle. Note the concave tread profile

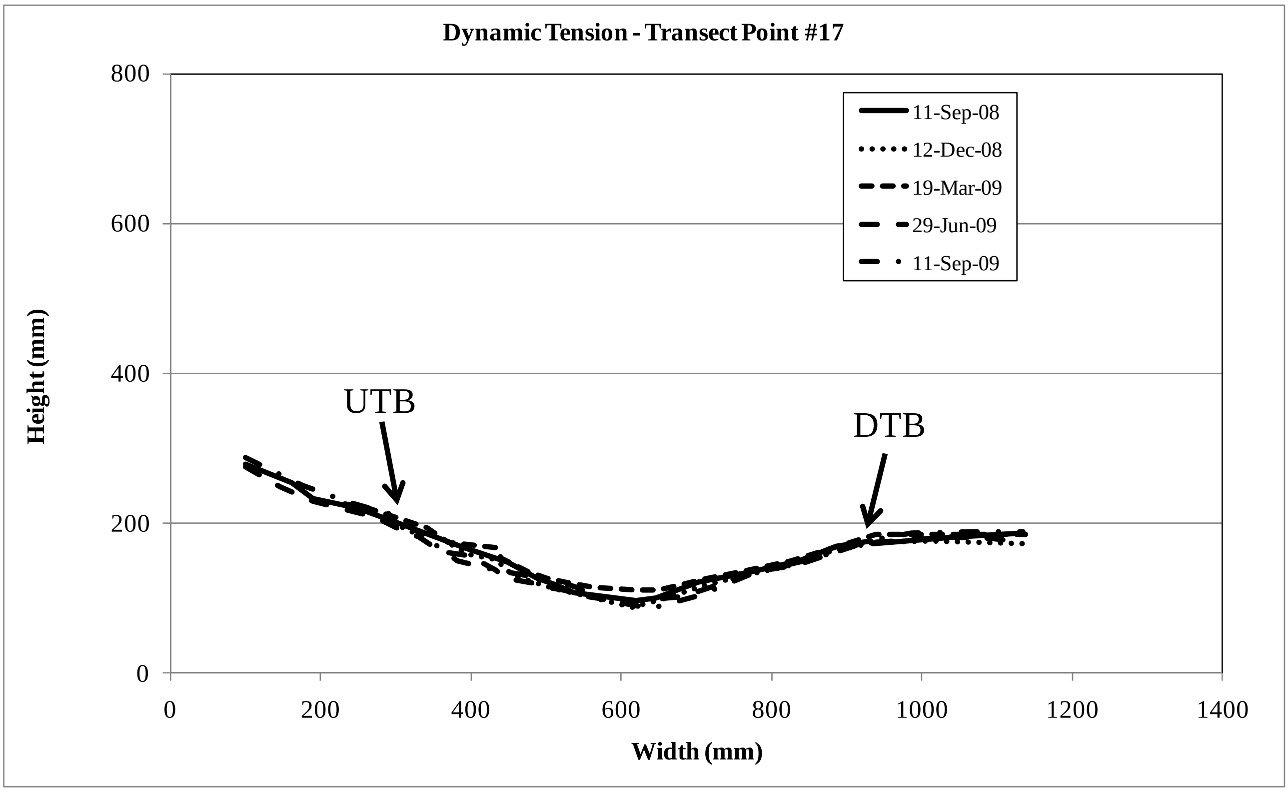

Figure 27 DT-17 profiles

9.18 DT-18

The measurements taken at this transect point in December 2008 were performed with the bar not set to horizontal correctly. This error was not apparent until the data was processed. The values were adjusted using basic trigonometry using the heights recorded over URP and DRP as the reference points. The profiles for this transect point are reasonably consistent with the mean change values indicating there may have been some soil loss then deposit over the course of the study though the last set of measurements in September 2009 were taken by a different field technician to those of the first four surveys.

The transect point is on a long descending (15 per cent) section of trail (about 40 metres to the uptrail grade reversal) and with the trail to fall line angle of about 60° and a concave tread there is a high likelihood that this part of the trail will carry some water in times of heavy rain. Rider braking would be minimal on this section when ridden in the nominated direction and the used tread width has not changed. The measurements are confounded as there was thick broadleaf vegetation on the areas between the tread boundaries and the measuring limits making precise measurements to the surface of the soil problematic for a few measurements.

Conclusion: minor, insignificant change (loss and gain).

9.19 DT-19

The transect point is on a straight portion of trail with gradient of 12 per cent towards the uptrail grade reversal 6 metres along the trail. The profiles are consistent and the mean change values are minimal. The trail to fall line angle is about 65°. The surface is packed soil and the used tread width has not changed.

Conclusion: no change.

9.20 DT-20

The transect point is almost at the end of the trail on a fairly steep (11 per cent), slightly curved section. The surface is packed soil with loose and embedded small stones. The profiles are consistent and the mean change values are within expected measurement variation. The tread is concave and the used tread width has narrowed by 23 per cent. The uptrail grade reversal distance is 4 metres. The trail to fall line angle is about 70°.

Conclusion: no change.

9.21 *Dynamic Tension* Summary

Of the 20 transect points on *Dynamic Tension*, eleven showed no change discernible using the measurement and observation techniques of this study. Seven showed minor but insignificant change. One showed soil loss from September to December 2008 and soil deposition from June to September 2009. The other transect point that showed significant change did so with soil loss between September 2008 and March 2009 after which the profile has remained stable.

10 Conclusions

Cross-country mountain bike trails in Australia are increasingly being built following the guidelines for sustainable trail building developed by the International Mountain Bicycling Association (IMBA) headquartered in the US. The guidelines are widely promoted by Mountain Bike Australia, the peak body for competitive mountain biking in Australia and by IMBA Australia. Two of the trails built in South Australia to the guidelines are *Dynamic Tension* in the Mt Crawford Forest, Cudlee Creek Native Forest Reserve and *Tunnel Vision* in Eagle Mountain Bike Park. Both are within easy driving distance from the CBD of Adelaide at 43 and 14 km respectively. The entire 600 m of the former and a 1 km section of the latter were subjected to a year-long monitoring and assessment program from September 2008 to September 2009.

The trails were selected because: (1) they were built to guidelines recognised internationally as producing the most sustainable trails; (2) a rider, once started would finish the trail and not take a detour – hence the entire trail would be subject to the same use; and (3) the trails were not to be subjected to maintenance work during the course of the study. Maintenance was carried out on a two metre section of *Tunnel Vision* during the study by a team preparing the trail for a race. The members of the team were unaware of the importance of not altering the trail during the study. Coincidentally and fortuitously, the alterations to the trail occurred at a transect point on the day of a survey. Hence there is a three-survey record of the transect point before the alterations and a three-survey record of the trail 'bedding-in'.

Rainfall was just under 700 mm at each of the sites over the year and the use on each trail is estimated at a mean 8 to 12 riders per day on *Dynamic Tension* and 25 to 30 riders per day on *Tunnel Vision*. These figures exclude the use of events: when these are included, the use figures are estimated at 14 and 45 riders per day for *Dynamic Tension* and *Tunnel Vision* respectively (approximately 5,100 and 16,400 riders per annum respectively). At three-monthly intervals (ie on five occasions), trail tread transect profiles were taken at 20 randomly-selected points on each of the two trails. Changes in used tread width were recorded concurrently with the transect profile measurements. Relevant topography parameters were measured at each of the transect points. These are: trail gradient and bearing; sideslope gradient and bearing; and fall line gradient and bearing. From these measurements, the trail to fall line angle at each transect point can be determined. The presence or otherwise of outslope was noted though not measured.

Because the position of the transect points was random some were sited on corners, some on straight parts of the trail, some on sloping sections, and some at grade reversals. The number of variables associated with transect point position (eg on a corner, on a straight etc) coupled with only 20 points for each trail means that grouping to produce meaningful statistical analysis within and between each group is impossible.

Overall, 37 (92.5 per cent) of the 40 transect points showed no change or showed minor, insignificant change (soil movement) over the course of the study. The remaining three transect points (7.5 per cent) showed significant change.

The probable reason for one of these to exhibit such change is that its related section of trail deviates too far from the guidelines for sustainable trail building. The transect point is on a section of trail constrained by an area of significant vegetation on the (nominal) left or downslope side. The transect point is on a short (about 17 m) section of trail with the upslope grade reversal distance about 10 metres. The transect point is at the steepest part of this section at about twenty per cent and the trail tread for about two metres upslope and about three downslope does not have outslope. The trail to fall line angle of 50° coupled with a sizable catchment area populated by grasses on the sideslope hillside to the right of the transect point could well induce water run-off to proceed for some distance along the trail rather than crossing the trail with minimal erosive effect. There was some soil loss between the March and July 2009 surveys when 47 per cent of the rainfall of the study period and about 18 per cent of usage occurred. There was no discernible change from the July survey to the September survey. The recommended technique of rock armouring would significantly increase the sustainability of this portion of trail.

The second transect point that revealed significant change over the course of the study exhibited both soil loss and gain. The point is at the foot of a descending, right-hand curve of the trail and is at a drainage point on the turn that leads several metres away into a left-hand descending turn. The trail gradients at either side of the transect point are 1 and 4 per cent. Soil loss occurred from September to December 2008 during which time the trail experienced about 12 per cent of rainfall and about 22 per cent of riders. Deposition occurred from June to September 2009 when 40 per cent of the rainfall and about 12 per cent of riders occurred. These changes resulted in a nett zero change in transect profile area over the study period. The surface is soil with embedded small stones that help secure the soil. The used tread width has not changed and the tread started with slight outslope and is now almost flat from sediment deposition at the drain point. The trail to fall line angle is about 60° and the trail upslope grade reversal distance is 17 m (in this case towards the start of the trail). The shape of the tread for about 10m on the uptrail side is concave and this, coupled with the low trail to fall line angle would not allow water to run off the trail but induce it to move down to the transect point.

Changes at the third transect occurred in the first half of the study and are mostly caused by the growth of a trailside tree affecting the line of riders. After the trimming of this vegetation, most riders returned to the original riding line that had previously been bedded in and no change was discernible over the latter half of the study during which time about 51 per cent of the usage for the study period occurred.

The most soil loss that occurred across a 1 cm wide strip at any one of the three transects that showed significant change would fit on a garden trowel. There was no evidence at any of the 40 transect points of deep gouging of the type caused by a single tyre.

Seventy per cent of the transect points show no change in used tread width, 25 per cent have become narrower and 5 per cent have become wider but none are wider than the tread of the trail as built. This shows that at least at 40 randomly-selected points on a total of 1.6 km of cross-country mountain bike trail built to IMBA guidelines that good design and construction will keep riders to the trail.

In summary, the physical properties (transect profiles and used tread widths) of trails built to IMBA guidelines indicate that for the most part trails can withstand the combination of up to 30 riders per day and 700 mm of rain per annum for at least one year with little impact on the trail surface or the width of the used portion of the trail. Some maintenance is likely to be required in those parts of trails that deviate too far from the guidelines.

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Appendices

Appendix A: MTB User Counts – TRAFx Counter Calibration and Records
Appendix B: Transect Point Topographies
Appendix C: Transect Profiles
Appendix D: Measures of Transect Profile Change